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SPECKLEGRAM DATA REDUCTION USING OPTICAL AND DIGITAL TECHNIQUES--ETC(U)
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SPECKLEGRAM DATA REDUCTION USING OPTICAL AND DIGITAL TECHNIQUES

Electro-Optics Technology Branch
Electronic Technology Division

November 1977

TECHNICAL REPORT AFAL-TR-77-203

Final Report for Period May 1974 to September 1976

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AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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This report describes the development of a specklegram data reduction system for automatically analyzing specklegram output. The basic design incorporates a PDP-11 minicomputer as an overall control center with various optical and electronic components interfaced to the computer. Typical data runs yielded 1-2 second turn around time for each specklegram data point and approximately 1-2 fringe resolution over a specific output halo.

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FOREWORD

The major goal of this program is the development of a breadboard in-house laboratory measurement system. In pursuing this objective many experimental results were obtained which shed light on some improvements that could be made toward further development of such a system. These results are presented in this report along with some tried designs and proposed designs. The system was designed to readout specklegram data and display the information in a readable format with an automated optical-digital set-up, thus reducing the analysis time greatly over existing methods. The overall system design and end results are discussed in this report, which will be a final report to the Air Force Flight Dynamics Laboratory under project 1367-02-12. Mr. Gene Maddux and Dr. Frank Adams were the scientific contacts from AFFDL.

I would like to thank Dave Flannery of AFAL/DHO-2 and Chuck Skinn of System Research Lab. for their assistance in pursuing these Program goals.

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SECTION I

INTRODUCTION

Near the beginning of FY74 Gene Maddux and Dr. Frank Adams of the Air Force Flight Dynamics Laboratory visited Tom Williamson and Dick Lane of the Air Force Avionics Laboratory seeking a feasible method for analyzing specklegram data with a semi-automated optical data processing system. A set-up, made up of existing in-house equipment including a desk calculator, digital voltmeter A/D converter, and a motor driven scanning detector, was constructed immediately in the Laboratory of Bldg 22B and after several test conclusions indicated that an optical processing system could be fabricated to meet the requirements of AFFDL. (A copy of the initial study is attached at the end of the report.)

In January 1974 Dr. Adams requested and obtained $24,000 of AFFDL Laboratory Director's Funding (LDF-74-1) to finance a joint program with AFAL for developing an automated data readout and reduction technique for laser speckle photography. AFFDL funding was used to procure equipment and AFAL provided the engineering manpower.

A plane of attack was then begun for which the following equipment was ordered at the beginning of FY75: Minicomputer, X-Y Translation Stage, 2 dimensional detector, A/D convertor, clocking circuit. The final delivery of equipment was received in May of 1975 and the fabrication was underway. This report gives the demonstration of the brassboard optical-digital system fabrication for performing data reduction of specklegram recordings.

SECTION II

STATEMENT OF PROBLEM

In the early 1970s several researchers in the United Kingdom showed that small in-plane displacement measurements could be made by using the inherent speckle properties of laser light and employing double exposure photography (References 1 to 6). Further development of this technique, called "Speckle Photography," has been pursued at the Air Force Flight Dynamics Laboratory (References 7 to 11). It was found that the speckle distribution change during stressed and unstressed conditions on specified surfaces gives a direct indication of the amount of surface motion present under stress. This recording process is performed with a single beam laser imaging system, and as many as 40,000 data points can be recorded on a 4 inch by 5 inch photographic plate with one double exposure. At this point it was realized that to use the high resolution recording to its utmost, a readout system had to be established to speed up the method for extracting the data in its entirety. The laboratory readout method used originally consisted of projecting the output fringes on a ground glass screen, then orienting a slow scanning detector orthogonal to the fringe lines, and scanning the detector while plotting directly onto an x-y recorder. This process has to be performed for each data point on a specklegram plate with the addition of one accurate method for scanning from data point to data point. The average point to point recording time could be as large as 5 minutes, thus requiring 140 hours to analyze a single plate.

Careful study has shown that to establish the speckle photography method as a feasible tool for performing non-destructive testing, the point to point data collection time, including the point to point scan time, must be 1 second or faster. At these rates, the maximum time required to read a specklegram plate at maximum resolution would be 1.5 hours. A faster time can be achieved with some modifications to the existing brassboard described in this report. The modifications are discussed in the section entitled "Conclusions with Alternate Solutions."

The problem of data reduction of specklegram output appears to be solvable by a digital-optical system, and with further experimentation, a time improvement and resolution improvement are realizable over the initial brassboard setup.

SECTION III

DESCRIPTION OF OPTICAL SETUP

Figure 1 is a graphical illustration of the optical section of the brassboard system used for reading out specklegram data provided by the Flight Dynamics Laboratory for experimental use. A Spectra Physics Model 124-A He-Ne Laser with 15 milliwatts of power and a 1 millimeter diameter beam is the light source for the system.

Two lenses with a 4 to 1 focal length ratio are required to reduce the laser beam diameter to its optimal operating size. Microscope objectives of 20 power and 5 power were chosen for this experiment. The lenses are oriented such that the distances between them equals $f_{20} + f_5$, thus the 1 mm collimated beam emerging from the laser enters the specklegram plate at .25 millimeters. A .25 millimeter beam was chosen because experimentation showed that a smaller beam would create large secondary speckle and a larger beam would reduce the inherent resolution of a data plate.

The specklegram plate is held in a plate holder attached to a 5 inch by 5 inch Yosemite x-y translation stage (Figure 2). The stage, with .0001 inch stepping resolution, mechanically positions the data plate to each new data point position, with two Slo-Syn stepping motors tied directly to the worm gear mechanism on the stage. Each step of rotation by the motors represents a .001 inch lateral motion of the stage and is controlled by the PDP-11 central processor tied to a specially built electronic circuit constructed in-house by AFAL. The details of the central processor software and control circuit are described in two later sections of this report.

A ground glass plate, ground with 10 micron Carborundum, serves as a projection screen from which the specklegram fringes are imaged. The ground glass screen can be vibrated as a means of reducing the unwanted secondary speckle noise. An opaque 1/2 inch diameter spot is placed

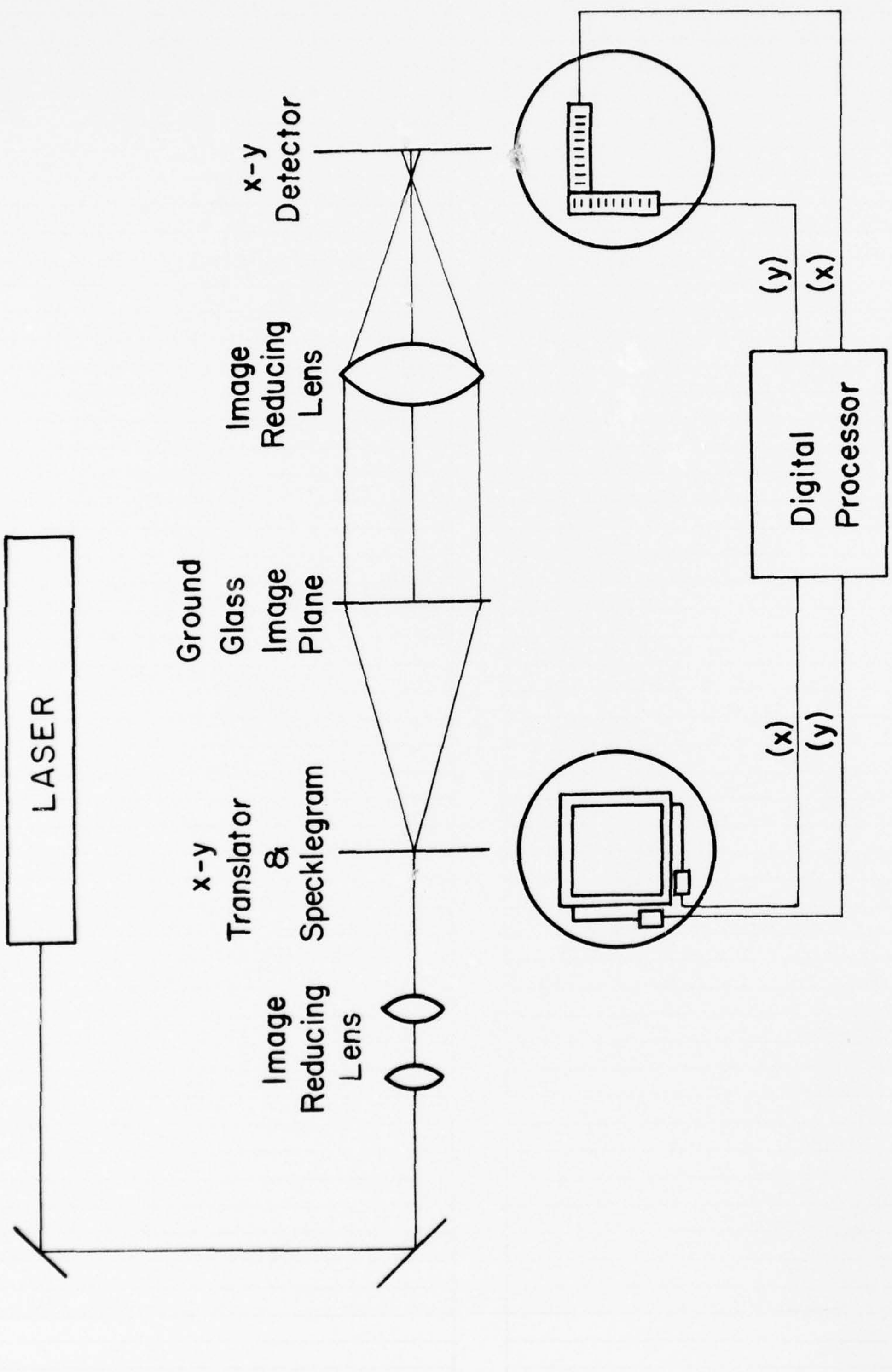

Figure 1. Graphical Description of Optical Setup

Figure 2. X-Y Stepping Stage

on the ground glass at the center of the speckle pattern canceling the D.C. component of the readout beam, in order to avoid detector saturation at the D.C. imaging point.

The primary speckle size used in constructing a specklegram determines the projection cone angle of the fringe pattern; thus as a ground glass screen is moved further from a specklegram the fringe size increases as the area of a plane, subtending a cone perpendicular to the cone axis. When sizing the secondary speckle to match the ground glass screen consistency, a hole of about six inches in diameter is optimal; thus an image reducing lens is required to project the proper fringe size onto the orthogonal detector assembly. A vivitar 28 Millimeter focal length lens is used for the brassboard system being described. Since specklegrams, as stress analysis tools, are produced with different imaging systems, varying reconstruction cone angles dictate that the optical geometry between the specklegram and detector

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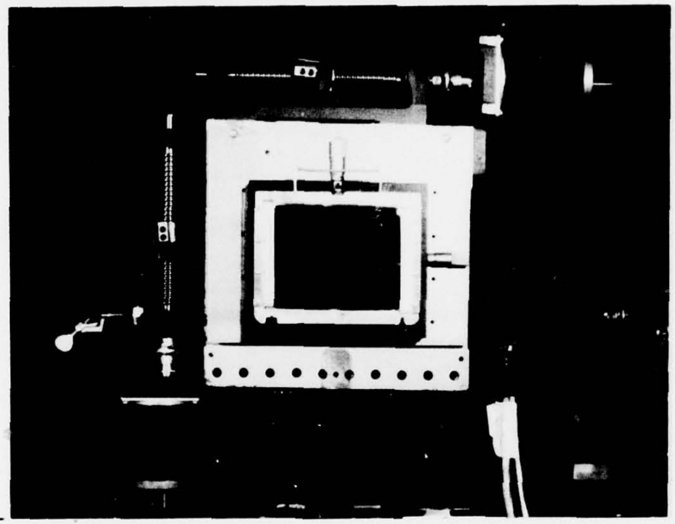

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FIG-2
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be variable. The ground glass screen and the detector assembly are positioned by two micrometer controlled slide stages.

Fulfilling the need for a medium to pick up the imaged fringe data is a custom built detector system consisting of two linear detector arrays and associated operating circuits (Figure 3). Appendix V gives a detailed description of the specification and operating procedures of a Reticon Corporation Detector System similar to the RL-64 WP Model incorporated in the optical setup. The circuitry for operating the detector consists of five main electronic sections: 1.) - 2.) Output drivers; 3.) Clocking circuit; 4.) - 5.) Sample and hold circuits. The output drivers, required for each linear array, simply amplify the output signal from each detector in the array to a 3 volt maximum during the light saturation operation. The amount of light required to reach saturation is obviously dependent on the length of time the detector is receiving light and, since the detectors integrated

Figure 3. Reticon Detector

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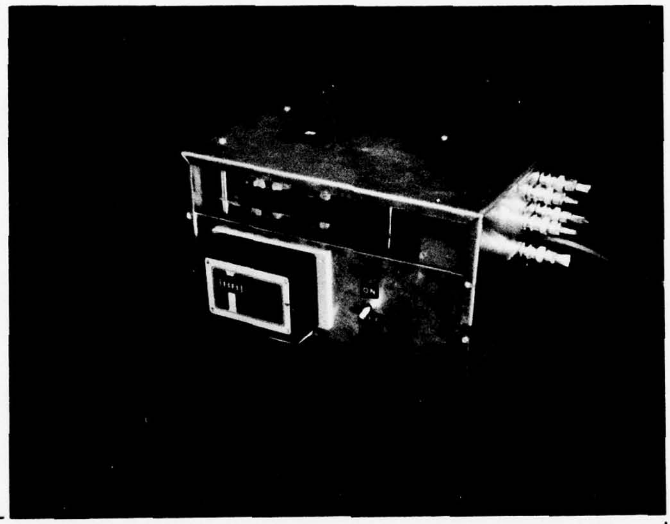

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all the incident light from one reading to the next, the scan time from detector to detector determines the optical saturation level. The clocking circuit which controls both detectors has a direct influence on the detector to detector read time. A more detailed description of the electronic circuit sequencing will be discussed in Section IV, 3. Circuits 4 and 5 are merely sample and hold electronics that read the output from the driver circuits and retain them for a time period long enough for an external readout. For instance, if the signal illustrated in Figure 4b were input to the sample and hold board it would emerge as shown in Figure 4a. In other words, a series of spiked pulses is transformed into a series of square wave pulses. At this point attention will be given to the configuration of the linear detector element relative to the optical fringe output. Figure 5 is a magnified view of the two linear detector arrays configured in a chip holder. The particular geometry chosen will allow the specklegram fringes to be projected onto the detector array at any angle but will make it still possible to determine the orthogonal spacing between fringes. By looking at Figure 6, we see that if the x and y axis represent the two linear detector arrays and the three skewed lines represent the fringe data, a simple trigonometric sequence allows us to determine the orthogonal spacing (d) and the fringe angle placement (θ) from the fringe spacing which appears on the detector arrays (x and y). The trigonometric sequence is as follows:

$$\theta = \tan^{-1} y/x$$
$$d = x \sin \theta$$
$$d = x \sin (\tan^{-1} y/x)$$
$$d = xy/\sqrt{y^2+x^2}$$
$$d = x / \sqrt{(1+(x^2/y^2))}$$

Thus, by employing two linear detector arrays set in a right angle field, a complete set of useful data can be extracted from any specklegram plate. The original detectors purchased from Reticon Corporation were 64 elements long, and since a maximum of 20 fringes

would ever enter the system, the Sampling Theory says 64 elements would suffice. But, it has been determined through experimentation that this number is too low to perform the job as accurately as required.

a

b

Figure 4. Reticon Output Samples

Figure 5. Magnified View of the Reticon Detectors Elements

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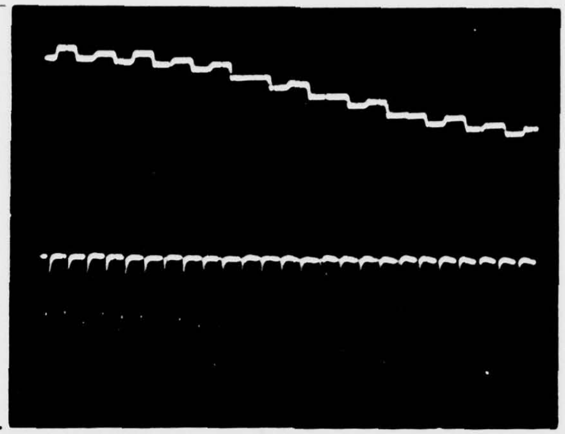

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FIG - 4

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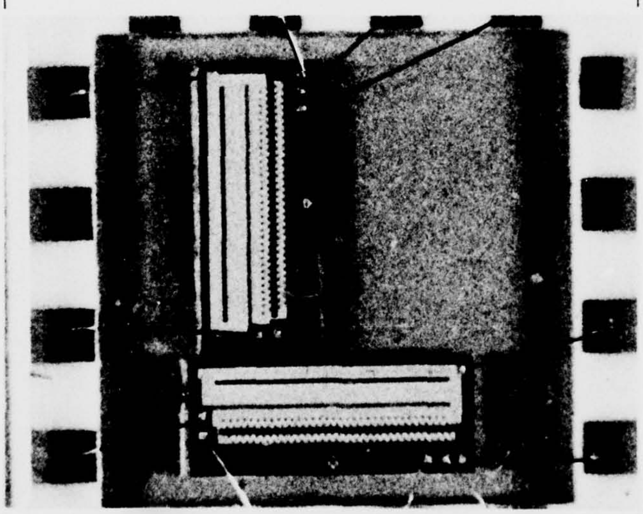

FIG - 5

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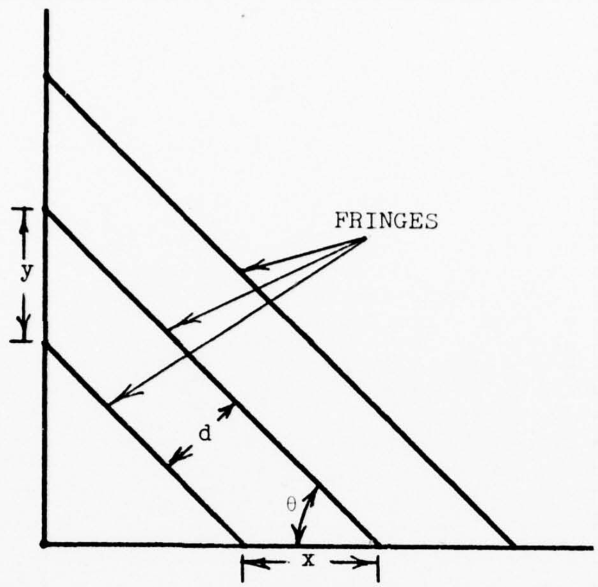


Figure 6. Graphical Description of Angle and Spacing Calculation

SECTION IV

DIGITAL AND ELECTRONIC SETUP

1. COMPUTER MODEL PDP-11-05

The nucleus of the entire specklegram analysis system is a Digital Equipment Corporation Model PDP-11-05 minicomputer with 4000 decimal word storage at 16 bits per word. The computer performs, under program control, all calculations on the incoming data, the stepping sequence of the x-y translation stage, the addressing of the detector, the scanning of the detector, and the retrieval of the data through an A/D converter. Figure 7 is a graphical layout of the processor and its peripheral hookup. A brief sequence of extracting data from a specklegram might be as follows: 1.) Load the plate into its holder and position it to a starting point at the edge of the data array. 2.) Set up the optics for the recorded magnification. 3.) Initialize all peripheral devices. 4.) Enter the x-y stage point differential (stepping resolution). 5.) Step the plate to its first data point. 6.) Address the detector array and perform the detector scan. 7.) A/D the serial data into core memory. 8.) Process the data into fringe spacing and angle. 9.) List the data to the teletype and, 10.) Step to the next data point and repeat the process. At the end of the complete process, the x-y scan parameters can be re-entered and a finer or coarser scan can be performed, based on the previous data run. At this point a more detailed discussion of the procedure for performing Steps 5 and 6 in the above sequence will be discussed.

2. X-Y STEPPING STAGE

The x-y stepping stage (Step 5) assembly consists of a Yosemite 5 inch by 5 inch translation stage, two Slo-Syn stepping motors, two Aerotech Drive Units, and a custom built plate holder mounted to the x-y stage. Stepping of the motors is accomplished by shifting pulses in a serial string to the motors. Each pulse rotates the motors 1.8° (200 pulses - 360°), and the polarity of the pulse determines the direction of motor rotation. The motor driving pulses and their

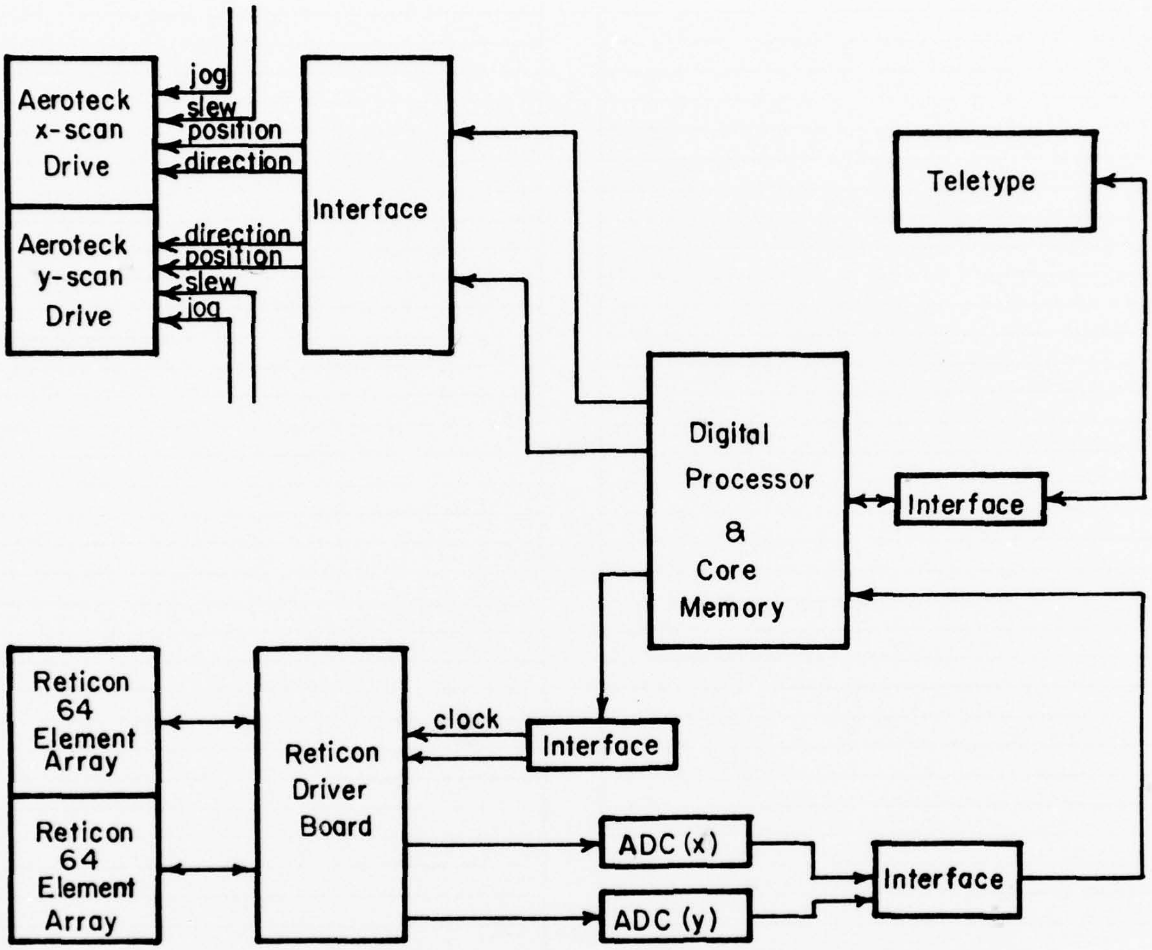


Figure 7. PDP-11 Computer and Peripheral Hookup

polarization are generated by the Aerotech Drive Units and only signals inherent to or input to these drive units will be discussed from this point on. For the case of externally driving the stage, it is required to apply separate 5 volt, 50 μsec pulses to the Aerotech Drive inputs for rotating the motors, and either a 0 or 5 volt signal to the direction inputs to dictate positive or negative direction of rotation. Each unit has the capability of running internally or externally, and in each case the number of pulses can be monitored by a digital readout on the front panel of the unit. Figure 8 shows the 2 Drive Units in their rack mount. During internal operation, for use in initializing plate position, the motors can be stepped in single pulse mode or in the slow mode; this will repetitively transmit pulses to the motors at a rate preset by a potentiometer on the front panel. Another necessary feature of the internal operation is the ability to reset the digital counter at any time during operation, which will create a zero start reference point. Thus, the drive units can be set to internal operation for initializing the x-y plate position, zeroing the digital meter, and then switching to the external mode for the minicomputer to take control.

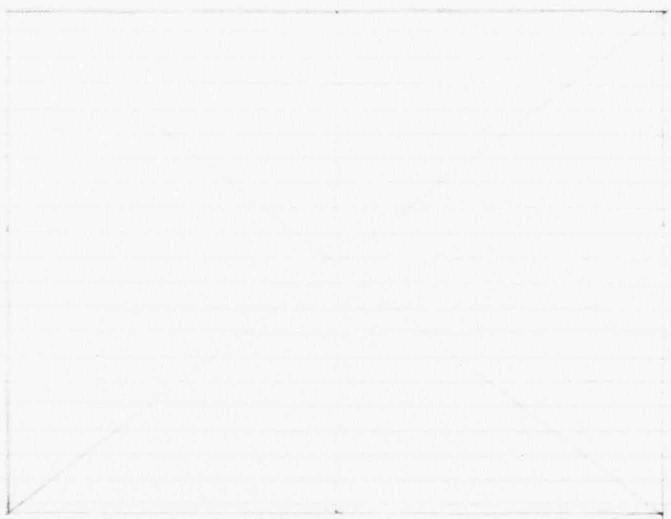
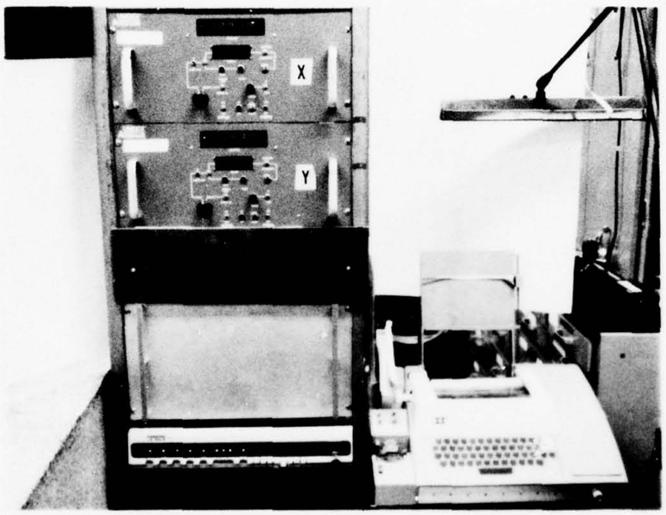


Figure 8. Digital and Electronic Hardware



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Since no commercial interface cards were available to drive the Aerotech Units externally, a computer interface was constructed in-house to generate the required driving signals. Figure 9 is a schematic of the interfacing circuitry.

Four signals had to be generated to drive the x-y stage under computer control, two directional signals and two scanning signals. For simplicity, discussion will be limited to only the x portion of the staging, assuming the y portion to be self-explanatory. The x-clock output supplies 50 μsec, 5 volt pulses to the x-drive unit as required, to drive the x-scanning motor. In order to get a pulse out to the x-clock line through the Figure 9 electrics, a signal has to be applied to lines D1 and E1, simultaneously activating the D303 one shot gate, which, depending on the capacitor value tied to the one-shot, will produce a low voltage 50 μsec pulse (capacitor = .022 μf). This output pulse is then amplified to a 5 volt pulse with an operational amplifier tied to a 5 volt, 1 kilohm resistive network. The problem now is to determine how the computer uniquely addresses the lines D1 and E1. D1 is hooked to V2 and an output from this AND gate is achieved by applying a signal on BUS D00, since the other gate input is always set high. The three BUS lines are simply binary outputs defined as follows:

WORD:	15	14 13 12	11 10 9	8 7 6	5 4 3	2	1	0
						BUS D02	BUS D01	BUS D00

where: the numbers 1-15 represent power of 2,

thus: 1 = BUS D00
2 = BUS D01
4 = BUS D02

E1 is hooked to the AND Gate with inputs S2 and N1. The details of these outputs can be referenced in the Peripheral Handbook under the M105

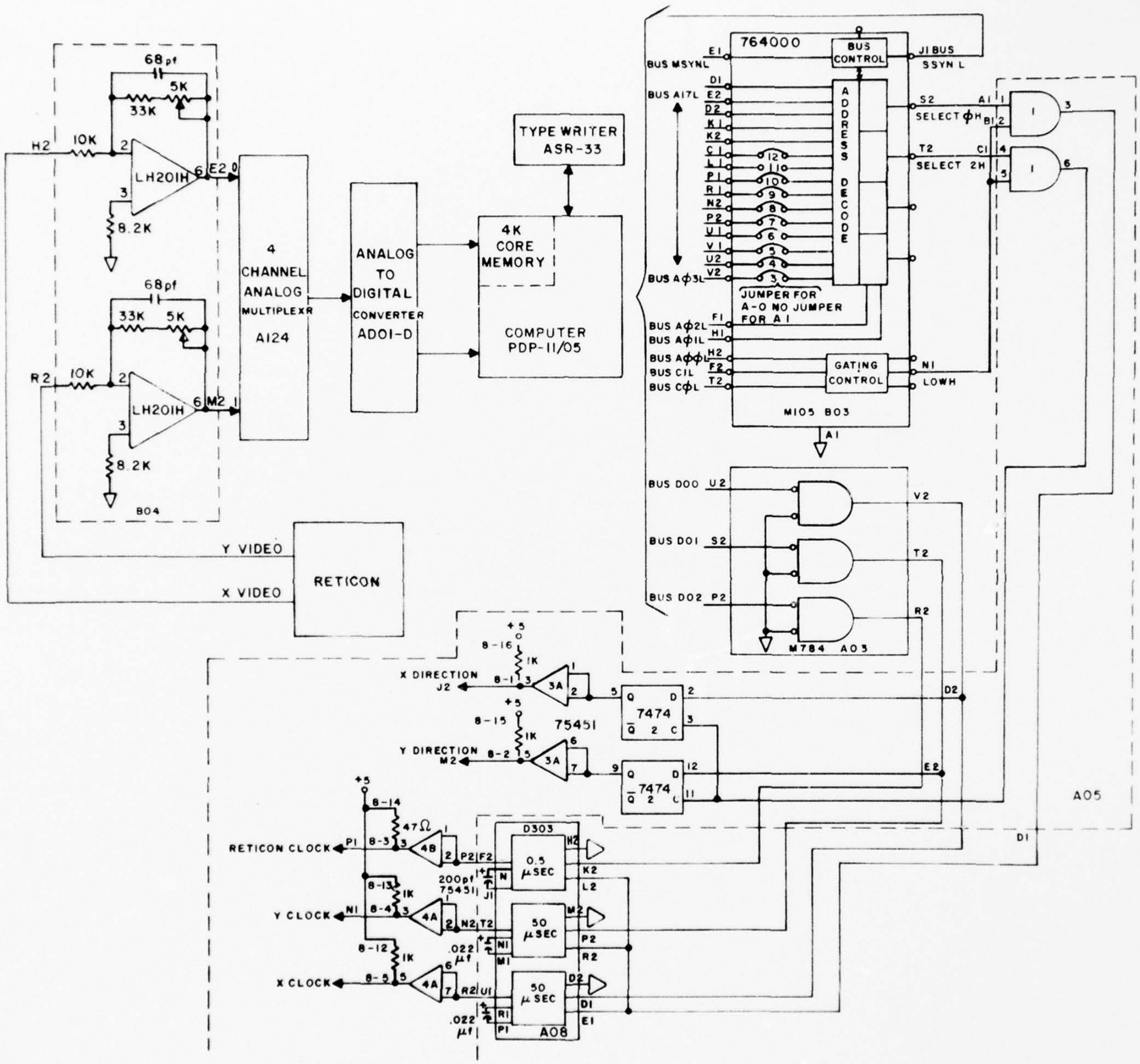

Figure 9. Peripheral Driving Electronics

circuit card chapter. For all practical purposes, in understanding this circuitry, the address to output a signal at point S2 is 164000 and at point T2 is 164002. In total, to get an x-clock output, the number 1 has to be moved to address 164000.

In a similar manner, a table can be constructed to summarize the four x-y stage outputs needed for computer control:

	OUTPUT	INPUT	ADDRESS
1.	x-clock	001 = 1	164000
2.	y-clock	010 = 2	164000
3.	x-direction	001 = 1	164002
4.	y-direction	010 = 2	164002

3. RETICON DETECTOR ARRAY

Since the specklegram has now been positioned for a data point readout, the detector has to be addressed to read the fringe data. A brief description of the Reticon Array operation would be of assistance at this point. For simplicity, the discussion will be limited to only one of the linear arrays, because the electronic inputs affect both arrays simultaneously.

Each linear array consists of 64 individually addressed detector elements, which are interrogated one at a time by a scanning clock and the charge accumulated by each element is read and cleared upon interrogation. These clock pulses can be generated internally by a separate clocking circuit at a preset rate or can be input to the clocking circuit from an external source at any rate up to 10 MHz, provided the pulses are at least .5 μsec in duration and 5 volts in amplitude. Whether from an internal or external clock source, the pulses must pass through additional circuitry to be counted for the purpose of generating start and end of scan pulses. The clocking circuit board has 12 binary switches (Figure 10) for setting the time delay (number of pulses delay) desired between readings, thus the maximum delay is $2^{13}-1$ (8191 pulses). At the end of each scan an end

Figure 10. Toggle Switch Configuration

of scan pulse is generated for external triggering and immediately before each scan a trig pulse is generated also for internal triggering. Referring to Figure 11, a typical scan for taking a single data reading is illustrated, with three lines of information. The top line represents the fact that the data is being read to the computer by a negative going pulse, the middle line shows the data itself, and the bottom line shows the end of scan pulses. As can be seen, there are actually two complete scans of the detector elements, before the third scan is read into the computer. The reason for the three scans is that, since the detectors integrate the light incident upon them up until they are interrogated, the first scan most likely will be saturated with ambient light as seen by the center scan at the far left of the figure. The second scan sometimes does not contain all 64 elements of detector information; thus the third scan is the first complete scan containing the data information only. An expanded view of the third scan computer reading, data display, and end of scan pulse is given in Figure 12.

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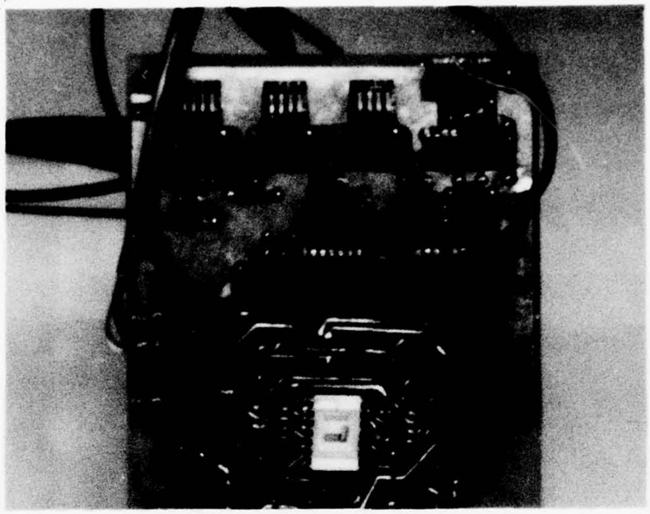

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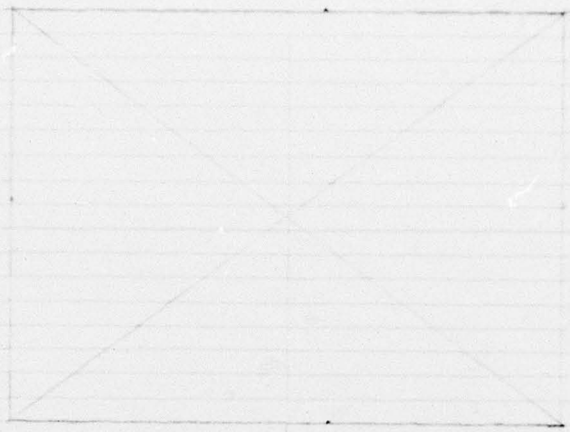

Figure 11. Clock Sequence for Read Initialization

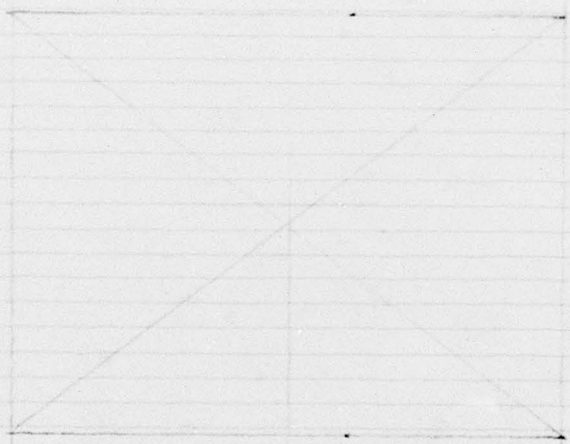

Figure 12. Clocking Sequence for Read Operation

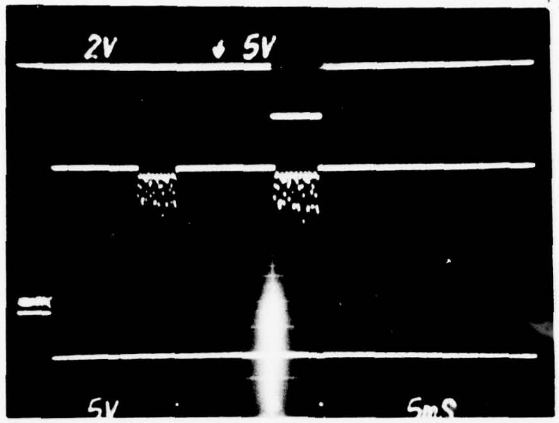

FIG - 11
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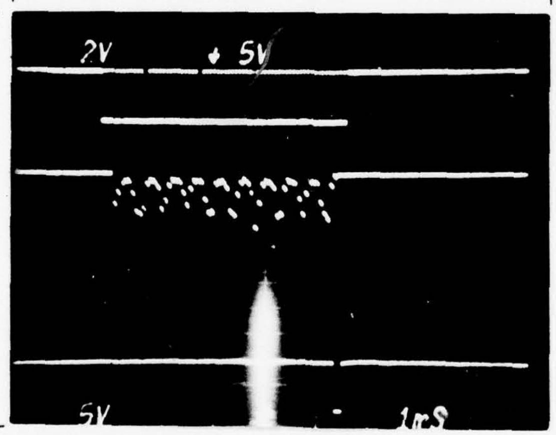

FIG - 12
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FIG - 11 + 12
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Referring to the schematic of Figure 9, let's now look at the circuitry built to generate the clock pulse and A/D the data to the computer. The same address decoder and input BUS word are used to generate the clock pulses.

OUTPUT	INPUT	ADDRESS
RETICON CLOCK	100 = 4	164000

A 200pf capacitor is tied to the the D303 one shot, giving a 5 μsec pulse output.

Special circuitry had to be constructed to match the Reticon data output to the input of the 4 channel Analog multiplexer (Model A-124). The multiplexer, A/D converter combination requires a Ø to 10 volt input swing to give the full 2^9 levels of digital resolution; thus a variable operational amplifier circuit is used to gain the maximum resolution of the A/D converter by taking the reticon 3 volt signals to the 10 volt maximum. The end-of-scan pulse is input to the 3rd channel of the multiplexer directly and is used to synchronize the software program to the detector and electronic hardware.

Two cash boards had to be attached to the outputs of the data from the reticon to act as a sample and hold circuit to maintain the data from each detector pulse long enough for the A/D converter to read its value. Figure 13 shows two data outputs before and after the cash board circuitry. Notice the short length of time the detector output remains peaked without the Cash Board.

Figure's 14, 15, and 16 are a few examples of 1,2, and 9 fringe outputs respectively. In the lower left hand corner of the figure is an oscilloscope trace of the reticon array output, with its analog to digital conversion data retrieved from computer core, to the immediate right and a graphical plot of the digital data is displayed above the computer printout. Notice how closely the detector output matches the graphical plot of the computer data.

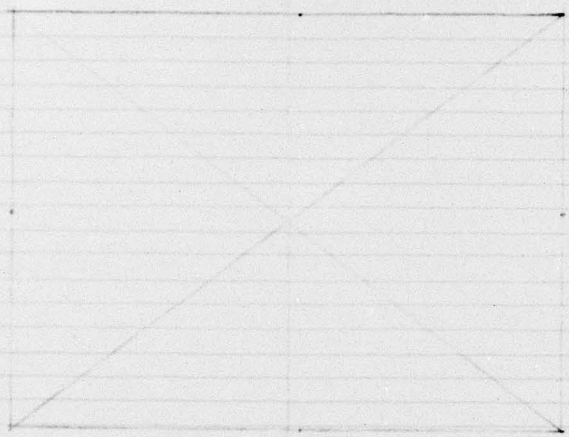

Figure 13. Sample and Hold Illustration

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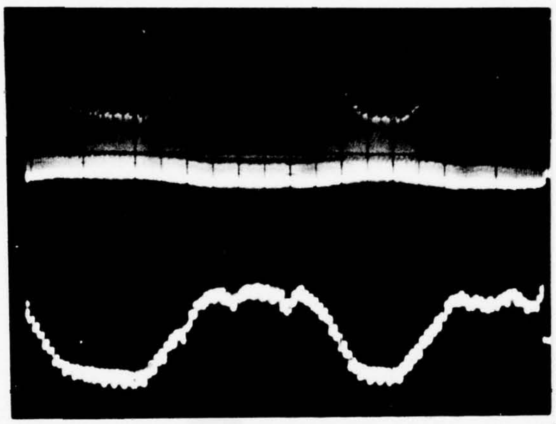

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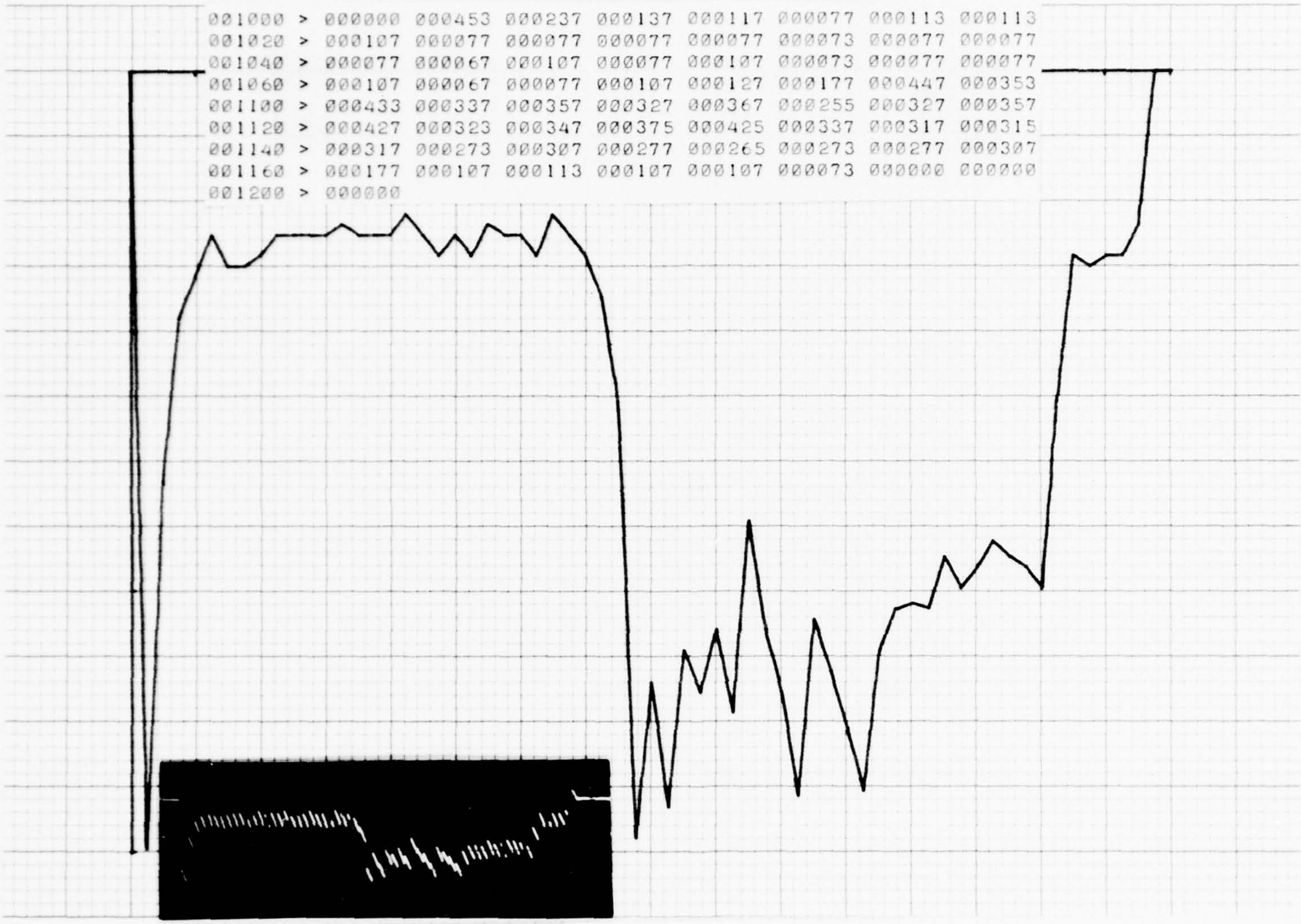
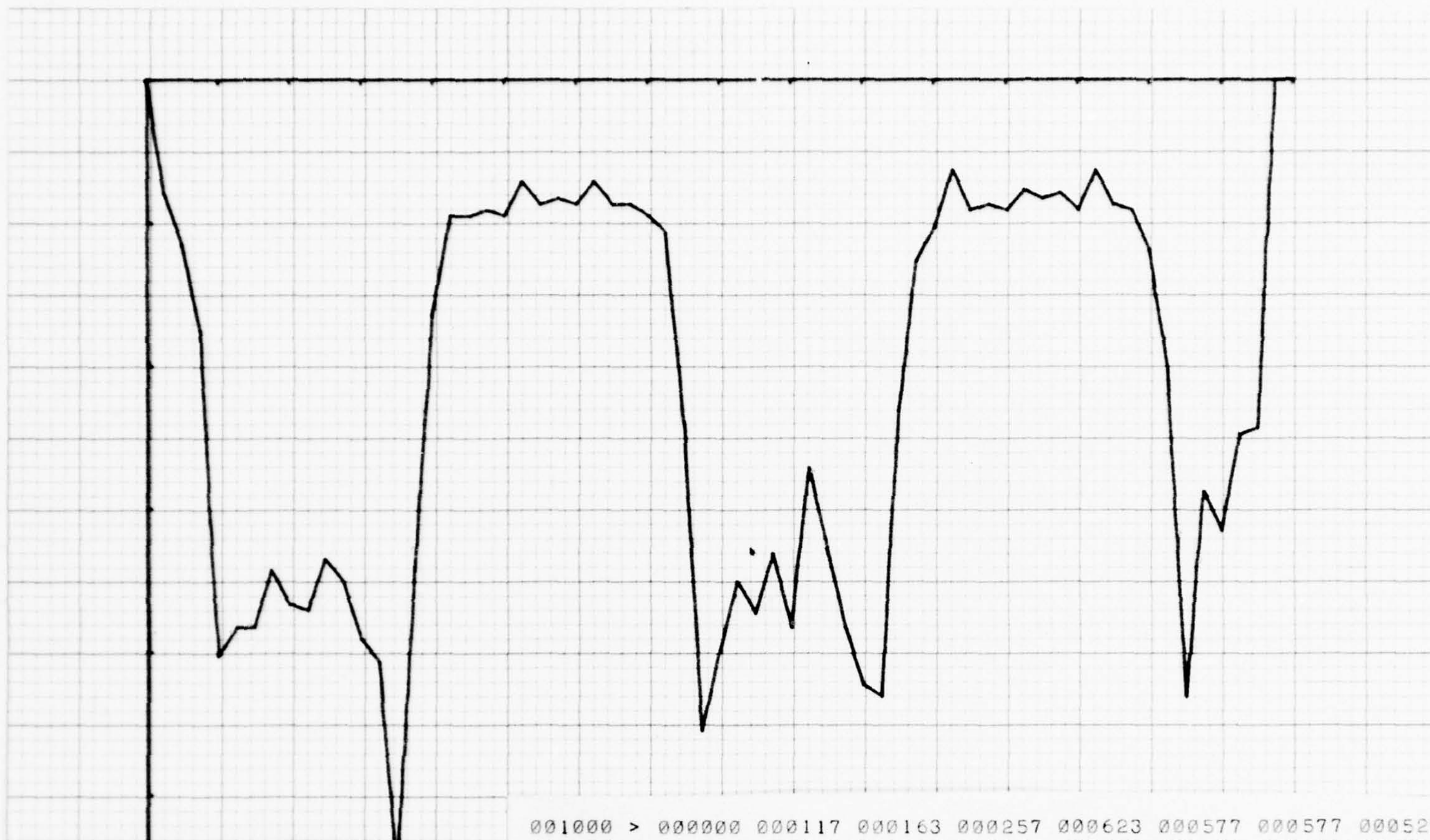
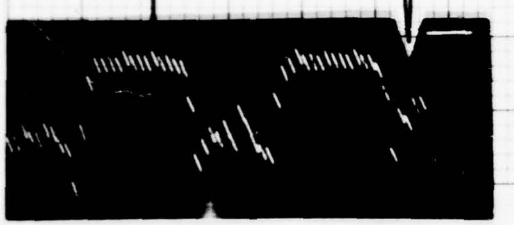


Figure 14. 1Hz Input Fringes With Reticon Plot and A/D Listing





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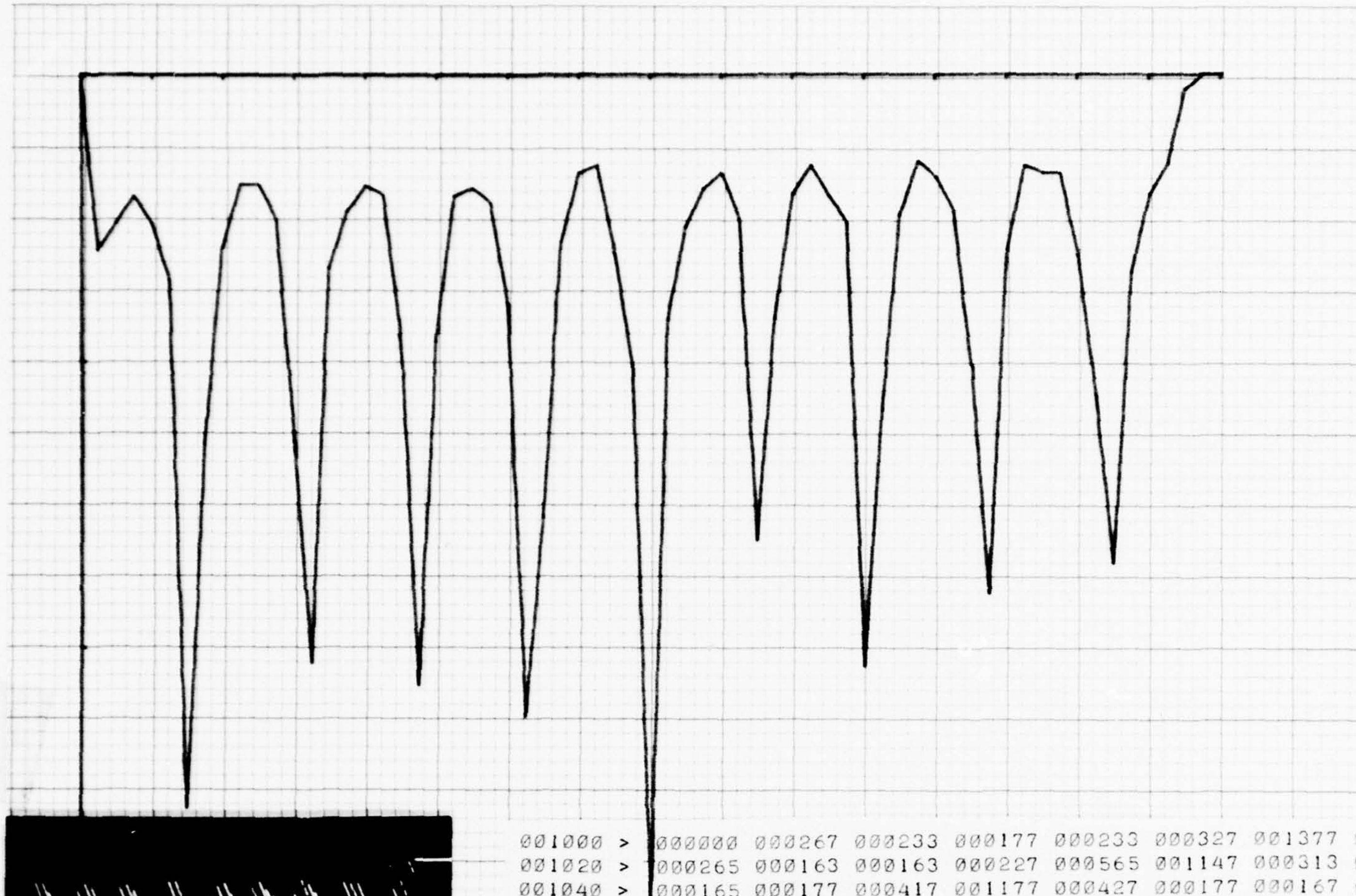
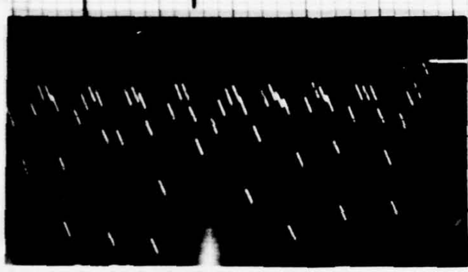
001000 > 000000 000117 000163 000257 000623 000577 000577 000527
001020 > 000557 000563 000517 000537 000607 000627 001053 000527
001040 > 000245 000137 000137 000133 000137 000107 000127 000123
001060 > 000127 000107 000127 000127 000137 000153 000357 000707
001100 > 000617 000537 000565 000513 000577 000417 000507 000577
001120 > 000647 000657 000347 000177 000147 000077 000133 000127
001140 > 000133 000115 000123 000117 000133 000077 000127 000133
001160 > 000167 000313 000657 000437 000473 000367 000363 000000
001200 > 000000
```

Figure 15. 2Hz Input Fringes With Reticon Plot and A/D Listing





```
001000 >  000000 000267 000233 000177 000233 000327 001377 000603
001020 >  000265 000163 000163 000227 000565 001147 000313 000217
001040 >  000165 000177 000417 001177 000427 000177 000167 000207
001060 >  000357 001237 000717 000257 000147 000137 000273 000457
001100 >  001537 000400 000237 000167 000147 000227 000747 000377
001120 >  000175 000137 000177 000233 001153 000537 000223 000133
001140 >  000153 000217 000457 001037 000267 000137 000147 000147
001160 >  000275 000517 000777 000317 000175 000135 000017 000000
001200 >  000000
```

Figure 16. 9Hz Input Fringes With Reticon Plot and A/D Listing

SECTION V

SOFTWARE

1. PDP-11 SOFTWARE FUNCTIONS

The PDP-11-05 family of minicomputers operates on simple 16 bit machine language with 7 registers for program manipulation, 2 of which are a stack pointer (R6) and a program counter (R7). The stack pointer acts as storage pointer for keeping track of subroutine jumps and the program counter keeps track of all addressing within a program, including automatic word or byte sequencing.

The method chosen for writing a program depends on the software compilation routine desired by the user to generate the machine language for computer operation. The highest level language that can be used is Fortran but many hardware options have to be tied to the computer hardware directly, and along with the high cost of the Fortran compiler software, a substantial cost increase is realized. Due to the limited budget available, the simplest of all languages was chosen, and other than creating a substantially more complex programming routine, this simple language proves to be adequate for doing the job. This simple language (assembly language) is comprised of the following programming commands:

1. CLR - clear
2. DEC - decrement
3. INC - increment
4. NEG - negate
5. TST - test
6. COM - complement
7. ASR - aritnmetic shift right
8. ASL - arithmetic shift left
9. ADC - add carry
10. SBC - subtract carry
11. ROL - rotate left
12. ROR - rotate right
13. SWAB - swap bytes
14. MOV - move
15. ADD - add
16. SUB - subtract

17. CMP - compare
18. BIS - bit set
19. BIT - bit test
20. BIC - bit clear
21. BR - branch
22. BEQ - branch on equal
23. BNE - branch on not equal
24. BMI - branch on minus
25. BPL - branch on plus
26. BCS - branch on carry set
27. BCC - branch on overflow set
28. BVS - branch on overflow clear
29. BVC - branch on less than
30. BLT - branch on greater than
31. BGE - branch on greater than or equal
32. BLE - branch on less than or equal
33. BGT - branch on greater than
34. BHI - branch on high
35. RTS - return from subroutine
36. JSR - jump to subroutine
37. HALT - halt
38. WAIT - wait for interrupt
39. JMP - jump

The modes available for applying the above commands are listed briefly on the following tables and are described in detail in the PDP-11 Processor Handbook.

MODE	R

MODE	NAME	SYMBOLIC	DESCRIPTION
Ø	REGISTER	R	R is operand
1.	REGISTER DEFERRED	(R)	R is address
2.	AUTO INCREMENT	(R) +	R is address; R + 2 → R
3.	AUTO INCREMENT DEFERRED	@ (R) +	R is address of address; R + 2 → R
4.	AUTO DECREMENT	- (R)	R - 2 → R; R is address
5.	AUTO DECREMENT DEFERRED	@ - (R)	R - 2 → R; R is address of address
6.	INDEX	X (R)	R + X is address
7.	INDEX DEFERRED	@ X (R)	R + X is address of address

MODE	7

MODE	NAME	SYMBOLIC	DESCRIPTION
2	IMMEDIATE	# n	operand n follows instr
3	ABSOLUTE	@ # A	address A follows instr
6	RELATIVE	A	instr address + 4 + X is address
7	RELATIVE DEFERRED	@ A	instr address + 4 + X is address of address

Three examples using the commands and modes listed above are given as follows.

MOV R1, (R2) +

$$\underbrace{0\ \ 001\ \ 000}_{\text{MOV}}\ \underbrace{001\ \ 010}_{\text{MODE R}}\ \underbrace{010}_{\text{MODE R}}$$

CMP # 426, @ (R4) +

$$\underbrace{0\ \ 010}_{\text{CMP}}\ \underbrace{010\ \ 111}_{\text{MODE 7}}\ \underbrace{011\ \ 100}_{\text{MODE R}}$$

0	000	000	100	010	110
0	0	0	4	2	6

CLR (R5)

$$\underbrace{0\ \ 000\ \ 101\ \ 000}_{\text{CLR}}\ \underbrace{001\ \ 101}_{\text{MODE}}$$

2. CONTROL PROGRAM SOFTWARE DESCRIPTION

Due to the limited commands and the lack of arithmetic functions, the software required to control the complete analysis system is quite complex and lengthy contrary to what might be expected when using a higher level language. The program can be outlined into 21 different sections or subroutines as follows.

1. PROGRAM START AND PARAMETER LOADING - START
2. ASC II AND DECIMAL TO OCTAL CONVERSION - ASC II
3. CONTROL - MANIP
4. FAST FOURIER TRANSFORM - FIT
5. DETECTOR READ - READ
6. DISPLACEMENT & ANGLE LIST - PRINT
7. ANGLE CALCULATION - ANGLE
8. AMPLITUDE CALCULATION - AMP
9. TELETYPE OUTPUT - TTYOUT
10. OPERATION SELECTOR - OPER
11. TELETYPE INPUT - INPUT
12. DISPLACEMENT CALCULATION - DISP
13. FRINGE FREQ DETERMINER - FREQ
14. OCTAL TO DECIMAL CONVERSION - OTD
15. X-Y STAGE CONTROL - STAGE
16. PRINT POSITION - POSITN
17. DATA BUFFERS - RRØ - STEPLY
18. PRINT BUFFERS - ASKAV - QUES
19. TRIG TABLE FOR ANGLE - TANBUF - SINBUF
20. TRIG TABLE FOR FFT - COS - SIN
21. SYMBOL TABLE - A - ZEROX

Each subprogram can be described briefly in the order that it appears in the overall program as follows:

1. TITLE merely sets a title heading for the program that appears at the top of each page.

5. ENABLE AMA sets the assembler to define the machine language in the Absolute Memory Addressing mode.

8 - 15 These lines define the labels assigned to the bottom 7 words of core in computer memory with register numbers, stack pointer, and program counter.

16 - 19 Lines define the labels assigned to the listed core locations 177560-177566 which address the input and output from the teletype terminal. KBS and TPS are merely status words and KBB and TPB are input and output buffers.

27. 500 is the starting address of the program.

28. START: This is the first line of the main program which assigns a stack pointer address.

30 - 31 Prints "No. of Data Averages" by addressing the TTYOUT Subroutine.

32 - 37 Loads ASC II value of No. of Averages to the "MEAN" buffer via the INPUT subroutine and then coverts the ASC II values to an octal value and stores it in the TIMES buffer.

39 - 42 Clears all buffers from X LIMIT to STEP-X in the data buffer subroutine called RRØ.

43 - 75 Prints enter, and convert to octal: "X-Tot Scan Distance," "Y-Tot Scan Distance," "X-Increment," and "Y-Increment," similar to the method described in lines 32 - 37.

68. Sets the direction of the X and Y scan to be positive. Referring to Figure 9, move a 4 to 164002 which moves zeros to 164002 through Bus D00 and D01, making the output to the direction lines 0 volts or "low" produce a positive direction.

76 - 77 Prints the header title as shown in the data section of this report.

78 - 79 Jumps to the subroutine "STAGE," which initiates the X-Y stepping stage.

80 - 81 Prints "X-Y SCAN COMPLETED."

83. Halts.

86 - 9Ø ASC II: Subtracts 60_8 from each ASC II entry; thus the member 61_8(ASC II for 1)-60_8 = 1_8 and 71_8(ASC II for 9)-60_8 = 11_8, which continues until a carriage return is received (#15).

92 - 94 Loads Least Significant Digit, which is already in octal format.

98 - 104 Converts 2nd digit to octal format as follows: Add 12_8 (10_{10}) to a dummy register for each unit value in the 2nd digit and then loads the final value to R3, which is the finish of the ASC II routine, and is the final octal value of the complete list of digits.

105 - 132 Converts the 3rd, 4th, and 5th digit in the same manner as in steps 95 - 104.

133 - 135 Stores final answer in OBUF.

138 - 142 Clears working registers and buffers from RRO to KEEP (lines 892 - 911).

143 - 140 Clears FBUFAV and FFTBUF.

147 - 153 Self explanatory.

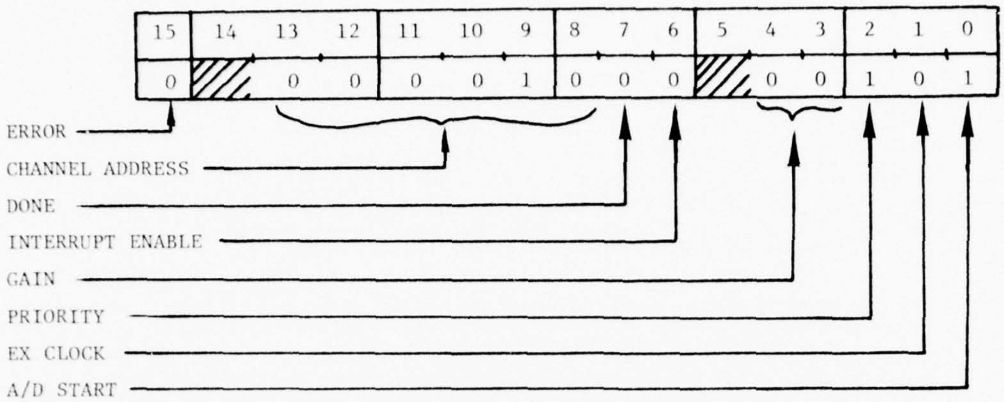
154 - 158 If the frequency is below 4 fringes then prints "LOW;" if not, then prints Go To a Frequency.

159 - 162 Changes Octal Frequency Count to Decimal Value and converts to ASC II Code; then prints value in Base 10 to Teletype Output Printer.

163 - 175 The first time through MANIP performed complete analysis on X direction of Detector data, and now the Y-direction data is analyzed through MANIP and printed out to TTYOUT.

178 - 462 FFT: Due to the complexity of the Fast Fourier Transform Routine details of its operation can be obtained from Mr. Lane of AFAL/DHO, and will not be covered in this report.

471. READ: Moves a clock pulse from the Electronics Unit schematically illustrated in Figure 9 to the clock input of the Reticon Array.



472. Moves the number 1005_8 to the control and status register (links the A/D converter to the software) which addresses channel 2 of the A/D converter, sets the priority level to 1 and starts the A/D operation.

473. Loads the CSR (Control and Status Register) to RØ.

474 - 475 Checks for the Done Bit of CSR (Bit 7), and if not sets return to DONE 1, otherwise must go to next line and load data.

476 - 478 Moves the data from channel 2, through data Register 176772, to register R1. Channel two is hooked to the detector end of scan (EOS) line which emits a pulse when a complete scan of the 64 detector elements is finished. After the data load, the program checks to see if the end of scan pulse has appeared. If not, branches to CLOCK 1.

479 - 482 Allows for 2 EOS pulses before continuing to the next program section.

483 - 487 Continues clocking the detector through the dead time between scans that are preprogrammed through the toggle switches on the clocking circuit board. The switches are set to

$$0000 \quad 1111 \quad 0011 \quad = \quad 227_{10}$$

Thus, it works out that 202, as programmed in the software, provides the proper delay to allow a data read at the correct time.

488 - 491 Is a software delay that allows a large enough time between clock pulses, for the pulse generator of Figure 9, to operate properly. If, for instance, the MOV # 4, @ # 164000 operation were performed in a small program loop, the pulses generated from the address decoder, arrive at too high a rate for the one-shot delay, thus exiting at the clock pulse output as a voltage level, not a pulse.

492 - 494 Decides whether to read the X detectors or the Y detectors.

495 - 500 The entire clocking routine previous to these steps were initialization procedures aimed at setting up the A/D converter to read data from the detector array at a time when meaningful data was present. These few lines read this unambiguous data and load it into core memory. (R4) is the storage medium where R4 points to either FFTBUF or FBUFAV.

505 - 512 If averaging of the data is desired, which is a buffer that designates a data load to either FFTBUF, or FBUFAV.

513 - 525 Repeats the data read operation for the Y-axis with the same logic as in steps 492-509.

526 - 540 Averages the data and loads the averaged data to the FFTBUF buffer. Since the averaging method probably does not appear obvious, a brief description follows: 523 - 525 TIMES contains the number of desired averages with TRACK incrementing with each average performed (TRACK = TIMES means done). 526 - 527 The data is loaded to FFTBUF from the first data read; 528 - 534 after first two data reads, each data buffer (FFTBUF: FBUFAV) is divided by 2 (ASR) added together and loaded to FFTBUF. 535 - 537 Prepares to load new data to FBUFAV for another average.

543 - 549 Allows for reduction of redundancy between first and second half of the detector active elements by loading the data stored for the first half of the detector into the storage location delegated for the second half.

555. PRINTS.

556 - 562 Clears the XDISTO and YDISTO buffers; then calculates the X-spacing from the X-frequency as follows: (f/No. of detectors = spacing) where f = ROBUF, No. of detectors = $64_{10} = 100_8$.

563 - 567 Same as above for Y-spacing.

568 - 576 Goes to Angle calculation subroutine; then returns and prints answer. Goes to Displacement subroutine; then returns and prints answer.

581. ANGLE.

582 - 593 Loads X and Y spacings; multiplies the Y spacing by 100_8 to obtain a whole-number output from the division of Y by X. The angle is calculated by:

$$\theta = \tan Y/X$$

594 - 599 Takes the value Y/X (stored in R0) and scans it through the tangent table (TANBUF), listed in one-degree increments, until the two values compare; then stores the comparison address to RATIO.

600 - 607 Clears DBUF then Jumps to Subroutine OTD and loads to DBUF.

612. AMP.

613 - 620 Loads start address for Real Part of FFT (FFTBUF) and imaginary Part of FFT (FFTBUF + 200). Checks to see if data point of real and imaginary are negative, if so make positive.

621 - 628 Squares the real data point amplitude.

629 - 641 Squares the imaginary data point amp.

637 - 641 Adds real and imaginary data points and moves to original real data point storage location and checks to see if all data points have been squared; if not, increment the FFTBUF addressed for real and imaginary and repeats the complete process starting at line 615.

651. TTYOUT.

651 - 656 Tests the Teleprinter Status; if read, moves data to Teleprinter Buffer and prints. Checks if finished printing by a 0 data point appearing.

661. OPER.

661 - 678 Checks if a given letter (S, X, Y, or D) was input from the Teletype and, if so, load R5 accordingly.

683. INPUT.

683 - 687 Checks the Keyboard Status and, if ready, moves the ASC II code of the desired key to R4; then clears the part bit (Bit 7) and moves the answer to address of (R0).

696 - 702 Prints correct character; checks if input is completed (#15 - Carriage Return) and moves a line feed to the printer (#12).

704. DISP.

704 - 707 Moves Sin Buffer address to R1 and adds RATIO to it. Ratio contains the address representation of the angle calculated in the ANGLE subroutine. Since the Displacement is calculated by

$$d = X \sin \theta$$

and the sin of θ can be calculated from a table similar to TANBUF, called SINBUF, which is also set up in one-degree increments; d is easily obtained by multiplying X by the value obtained from the SINBUF table.

708 - 723 Multiplies X DISTO by sin θ and divides the answer by 100_8 since SINBUF value is premultiplied by 100_8; then the answer is changed to decimal and control is returned to PRINT.

727. FREQ.

729 - 731 Checks for a high amplitude D.C. component in the FFT Data; if lower than 156, sets HIDC.

732. FFTBUF + 140 represents a fifteen Hertz frequency bin and, for determining the frequency, it is assumed that no frequency will be higher than 15 Hz or 15 fringes.

733 - 738 Checks for highest amplitude frequency bin by comparing the amplitude of the presently addressed bin to the maximum amplitude of all the previously searched bins; if larger goes to HOLD. If it is smaller, increments the next bin and either returns to search at SRCH or moves to QUIT if all bins have been searched.

739 - 747 For HIDC, checks data with #10 amplitude; if below GTO QUIT - 6.

748 - 750 If frequency was valid, loads address to R2 and the amplitude to R3, the increment between data point scans.

753 - 757 If no frequency was stored (R3 - 0), then moves 1 to NONE.

758 - 765 Looks at amplitudes on both sides of the highest amplitude frequency bin (R3) and determines if the actual frequency is slightly higher or lower than R3 by loading 1 to R5, if above; and loading 0 to R5, if below.

766 - 769 Since FFTBUF + 200 is 0 frequency and each bin in the FFTBUF is one cycle, then subtracting R2 from FFTBUF + 200 and dividing the answer by two, results in the final frequency in Hertz.

770 - 777 Loads the frequency to OBUF and a + or - to OBUF + 2. Returns control MANIP.

786. OTD.

786 - 822 Changes data in OBUF to a base 10 equivalent; then converts to ASC II code for printout.

827. STAGE.

832 - 840 MOV #1, @ # 164000 sends a X-clock pulse to the X-Y stage driver. Unit keeps track of the number of pulses transmitted for each scan between data points, whereas LINE keeps track of the total number of pulses transmitted to the total X-scan for one line. DELAY simply stores a programmed delay to allow the pulses to zero before another signal appears. Unit is compared to STEP X which contains the data determining the increment between data point scans.

845 - 848 Checks to see if the end of line distance is reached; if so, Branch to ZEROX.

865 - 873 Changes the sign of X and sends pulses to drive the X unit until the X position is 0 or its original position. A long delay is required (40000) before further execution of scanning to allow for experimental stabilizing. At this point the X sign is changed again and a Y scan is performed.

883. POSITN.

883 - 886 Clears the Decimal Buffer (DBUF).

887 - 890 Loads the X-position in octal and converts to decimal for terminal printout.

891 - 896 Same as above for Y-position.

897 - 900 Reloads the data point scan separation and returns to STAGE subroutine.

The last two pages of the program are a table showing the numerical address assigned to all Labels in the program.

The description of the software for operating the overall System, has been explained only in brief for the purpose of this report and a more detailed discussion can be planned upon request by the Flight Dynamics Laboratory.

SECTION VI

DATA

In this section of the report we will discuss the individual data shown in Figure 17 through 30 and the significance of the overall data collection as presented in the Results Section. A complete data collection operation had not been performed at the writing of this report, but shortly thereafter, it was anticipated that a complete set of data would become available for listing to the Flight Dynamics Laboratory.

The first method pursued for analyzing specklegram data was to look for amplitude peaks or nulls in the detector scanned data signals and average the distance between each peak or null by counting the number of detectors lying between them.

For initial experimental trials a set of fringe negatives were constructed photographically to input to the optical systems as a sample of high contrast fringes for setting up the computer software. Some data from these initial runs is shown in Figures 17, 18, 19, and 20. Frequencies of 5 Hz, 6 Hz, 7 Hz, 8 Hz, 9 Hz, 10 Hz, 20 Hz, 30 Hz, and 40 Hz were the photographic inputs. As can be seen, the system operated nearly flawlessly for these types of fringe inputs. At this point some real fringe data was input to the optical system and a couple of the best data runs are shown in Figures 21 and 22. Notice the variance in what appears to be peaks or nulls in the digital data printout. The data for most cases was less impressive than that shown, thus a new method for counting the fringe data had to be established.

Coincidental with our search for a new method of analysis, an electronics equipment oriented company made available an FFT (Fast Fourier Transform) operator for demonstration. This turned out to be the opportunity we needed to see if an FFT program would solve some of the problems we had encountered during peak detection. A typical specklegram data was projected onto a Reticon Array that we supplied and input to the FFT hardware they supplied.

PEAK REGISTERS

00001
00024
00063

PEAK REGISTERS

00015
00054
00065

PEAK REGISTERS

00001
00035
00065

PEAK REGISTERS

00008
00047
00065

5 Hz

PEAK REGISTERS

00001
00018
00051
00065

PEAK REGISTERS

00016
00049
00065

PEAK REGISTERS

00005
00038
00065

PEAK REGISTERS

00012
00045

6 Hz

Figure 17. Data Runs With High Contrast, Ideal Fringe Pattern

PEAK REGISTERS

00013
00041
00065

PEAK REGISTERS

00001
00028
00056
00065

PEAK REGISTERS

00011
00039
00064

PEAK REGISTERS

00001
00023
00052
00065

7 Hz

PEAK REGISTERS

00005
00029
00054
00065

PEAK REGISTERS

00001
00019
00043
00065

8 Hz

PEAK REGISTERS

00001
00017
00038
00060
00065

PEAK REGISTERS

00008
00029
00051
00065

9 Hz

Figure 18. Data Runs With High Contrast, Ideal Fringe Pattern

```
PEAK REGISTERS

ØØØØ8
ØØØ27
ØØØ47
ØØØ64

                10 Hz

PEAK REGISTERS

ØØØØ1
ØØØ16
ØØØ35
ØØØ55
ØØØ65

PEAK REGISTERS

ØØØØ3
ØØØ13
ØØØ23
ØØØ32
ØØØ42
ØØØ52
ØØØ62
ØØØ65

                20 Hz

PEAK REGISTERS

ØØØØ3
ØØØ13
ØØØ22
ØØØ32
ØØØ42
ØØØ52
ØØØ62
ØØØ65

PEAK REGISTERS

ØØØØ3
ØØØØ9
ØØØ16
ØØØ22
ØØØ29
ØØØ36
ØØØ42
ØØØ49
ØØØ55
ØØØ62
ØØØ65

                30 Hz

PEAK REGISTERS

ØØØØ3
ØØØØ9
ØØØ16
ØØØ22
ØØØ29
ØØØ35
ØØØ42
```

Figure 19. Data Runs With High Contrast, Ideal Fringe Pattern

```
PEAK REGISTERS

ØØØØ4
ØØØØ9
ØØØ13
ØØØ18
ØØØ23
ØØØ28
ØØØ33
ØØØ38
ØØØ43
ØØØ48
ØØØ53
ØØØ58
ØØØ62
ØØØ65

                40 Hz

PEAK REGISTERS

ØØØØ3
ØØØØ8
ØØØ13
ØØØ18
ØØØ23
ØØØ28
ØØØ32
ØØØ37
ØØØ42
ØØØ47
ØØØ52
ØØØ57
ØØØ62
ØØØ65
```

Figure 20. Data Runs With High Contrast, Ideal Fringe Pattern

```
PEAK REGISTERS

   00007
   00022
   00040
   00056
   00069

001554 > 000000 000000 000000 000000 000000 000107 000137 000147
001574 > 000237 000427 000757 000477 000577 000377 000457 000307
001614 > 000157 000107 000127 000117 000107 000077 000117 000123
001634 > 000157 000167 000427 000657 000763 000573 000553 000577
001654 > 000673 000323 000225 000153 000133 000107 000117 000113
001674 > 000115 000077 000157 000227 000553 000773 000527 000475
001714 > 000667 000417 000247 000147 000137 000077 000117 000117
001734 > 000117 000077 000133 000213 000477 000777 000657 000563
001754 > 000545 000337 000327 000000 000015 000012 000015


001772 > 000007 000026 000050 000070 000105 000012 000015 000000
002012 > 000000 000000 000000 000000 000000 000000 000000 000000
002032 > 000000 000000 000000 000000 000000 000000 000000 000000
002052 > 000000 000000 000000 000000 000000 000000 000000 000000
002072 > 001657


002074 > 000107 000137 000147 000157 000107 000127 000117 000107
002114 > 000077 000117 000123 000157 0001[illegible]7 000153 000133 000107
002134 > 000117 000113 000115 000077 000157 000147 000137 000077
002154 > 000117 000117 000117 000077 000133 000000 000015 000000
002174 > 000000 000000 000000 000000 000000 000000 000000 000000
002214 > 000000 000000 000000 000000 000000 000000 000000 000000
002234 > 000000 000000 000000 000000 000000 000000 000000 000000
002254 > 000000 000000 000000 000000 000000 000000 000000 000000
002274 > 001566


002276 > 001570 001572 001574 001616 001620 001622 001624 001626
002316 > 001630 001632 001634 001636 001640 001664 001666 001670
002336 > 001672 001674 001676 001700 001702 001724 001726 001730
002356 > 001732 001734 001736 001740 001742 001764 001766 000012
002376 > 000000 000000 000000 000000 000000 000000 000000 000000
002416 > 000000 000000 000000 000000 000000 000000 000000 000000
002436 > 000000 000000 000000 000000 000000 000000 000000 000000
002456 > 000000 000000 000000 000000 000000 000000 000000 000000
002476 > 042520
```

Figure 21. Data Runs With Real Specklegram Data

```
PEAK REGISTERS

   00009
   00021
   00034
   00047
   00061
   00069

001554 > 000000 000000 000000 000000 000000 000137 000137 000127
001574 > 000117 000077 000127 000213 000477 000467 000377 000357
001614 > 000417 000137 000127 000133 000117 000077 000127 000127
001634 > 000247 000577 000737 000615 001033 000477 000227 000147
001654 > 000153 000077 000127 000127 000217 000457 000757 000707
001674 > 000653 001113 000473 000177 000157 000077 000133 000117
001714 > 000137 000127 000377 000647 000537 000427 000633 000377
001734 > 000217 000123 000157 000127 000117 000107 000177 000377
001754 > 000647 000347 000253 000000 000015 000012 000015


001772 > 000011 000025 000042 000057 000075 000105 000012 000015
002012 > 000000 000000 000000 000000 000000 000000 000000 000000
002032 > 000000 000000 000000 000000 000000 000000 000000 000000
002052 > 000000 000000 000000 000000 000000 000000 000000 000000
002072 > 001657


002074 > 000137 000137 000127 000117 000077 000127 000137 000127
002114 > 000133 000117 000077 000127 000127 000147 000153 000077
002134 > 000127 000127 000177 000157 000077 000133 000117 000137
002154 > 000127 000123 000157 000127 000117 000107 000177 000000
002174 > 000015 000000 000000 000000 000000 000000 000000 000000
002214 > 000000 000000 000000 000000 000000 000000 000000 000000
002234 > 000000 000000 000000 000000 000000 000000 000000 000000
002254 > 000000 000000 000000 000000 000000 000000 000000 000000
002274 > 001566


002276 > 001570 001572 001574 001576 001600 001602 001620 001622
002316 > 001624 001626 001630 001632 001634 001654 001656 001660
002336 > 001662 001664 001704 001706 001710 001712 001714 001716
002356 > 001720 001740 001742 001744 001746 001750 001752 001764
002376 > 001766 000012 000000 000000 000000 000000 000000 000000
002416 > 000000 000000 000000 000000 000000 000000 000000 000000
002436 > 000000 000000 000000 000000 000000 000000 000000 000000
002456 > 000000 000000 000000 000000 000000 000000 000000 000000
002476 > 042520
```

Figure 22. Data Runs With Real Specklegram Data

Figure 23 is a four plot sequenced illustration of the result of this mock setup. The first plot shows the specklegram data after and before averaging 512 times (top and bottom respectively). The second plot shows the first FFT with a strong peak to the far left and a secondary peak to its immediate right. The first peak turned out to be the reticon clock frequency and the second peak the actual data frequency. The third plot shows the clock frequency filtered out, thus rendering the strongest frequency peak to be 4.2 KHz instead of the 200 Hz Reticon clock frequency. Plot four shows the inverse transform of the FFT data giving back a signal with the same frequency as plot number 1. Thus it was concluded that the FFT approach would become the solution to the problem.

After an extensive amount of programming was performed to implement an FFT software routine, the photographic fringes were introduced into the system. Figures 24, 25, 26, 27, and 28 show a data run with different frequencies introduced into the x and y detectors of the Reticon Array. Notice please, that each frequency calculated is as nearly right as can be interpreted from the Reticon detector plot shown on the scope traces. The pluses and minuses listed before each frequency indicated whether the frequency displayed is slightly higher or lower than the frequency printed.

The computer listing of Figure 29 is a typical teletype printout obtained during a data run with the software advanced as far as it is today. The first question asks if the user wants a list of the FFT data. The second question asks how many times he wants the fringe data input and averaged before performing the FFT. "OUTPUT" asks if an x or a y detector scan is desired. The next few questions set up the scanning parameters for the x-y scanning stage, and are self-explanatory. At this point the computer takes over and prints out the x and y position of the data plate in the x-y translation stage, the calculated value for the frequency of the fringes, and a "LIST," which is merely a listing of the Fourier Transform of the averaged data, so as to determine if the calculated frequency agrees with the Transform data.

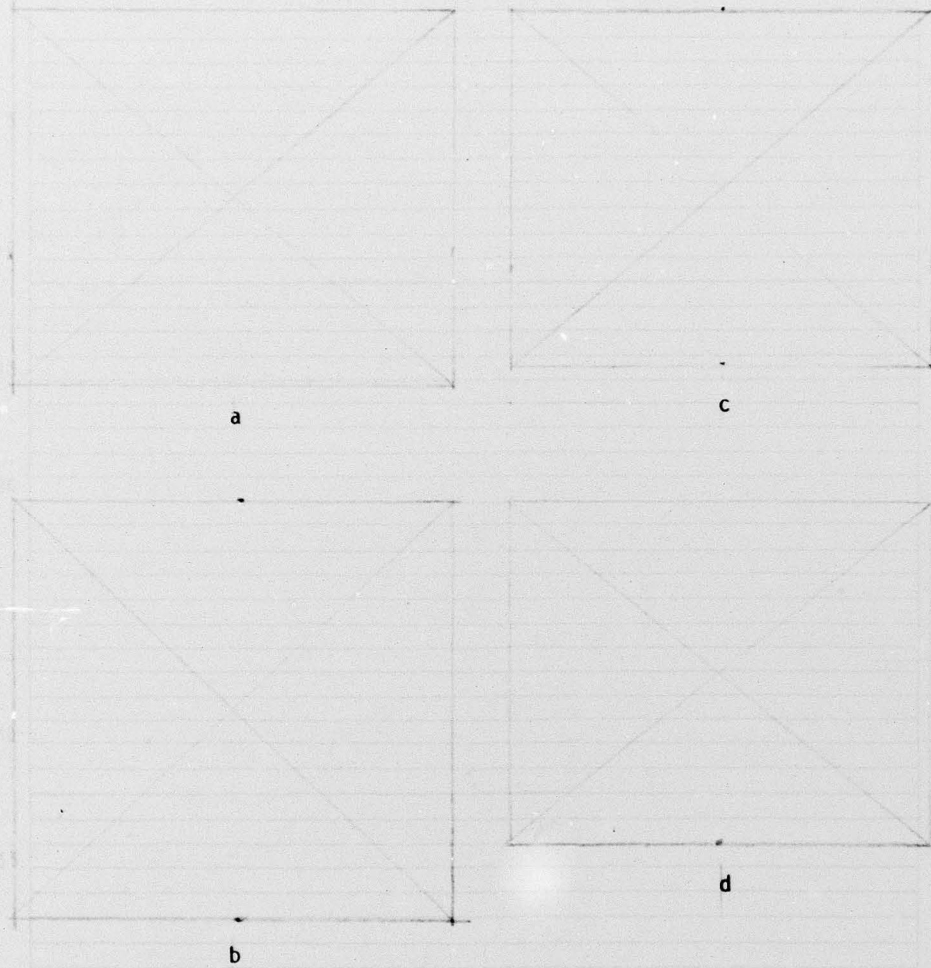


Figure 23. Sample Data Analyzed With Hardware FFT

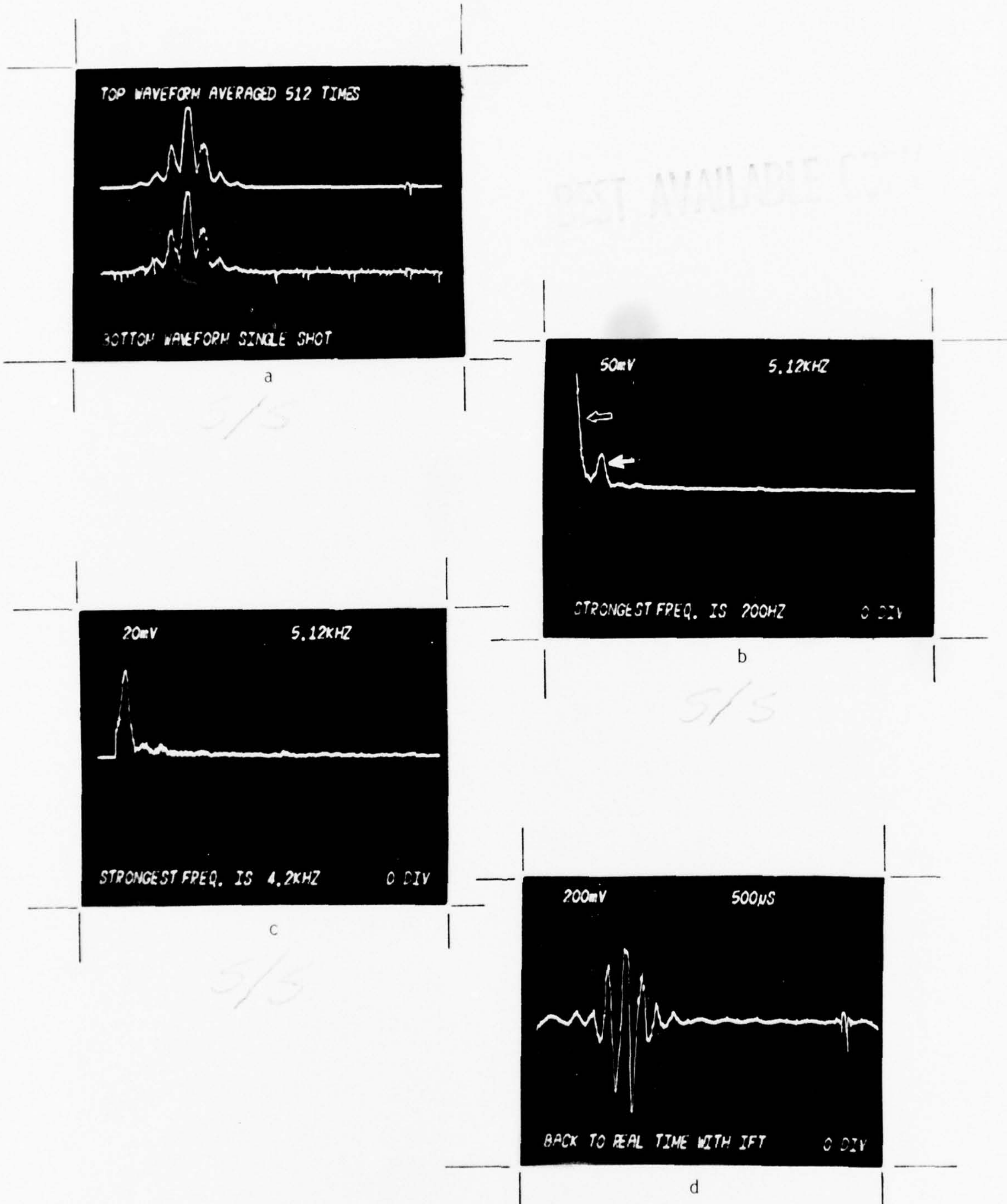


FIGURE 23. SAMPLE DATA ANALYZED WITH HARDWARE FFT

AFAL-TR-77-203
FIG-23, a, b, c+d
PAGE-42

```
OUTPUT ? X
FREQUENCY= -00010
-

OUTPUT ? Y
FREQUENCY= +00003
+

OUTPUT ?
```

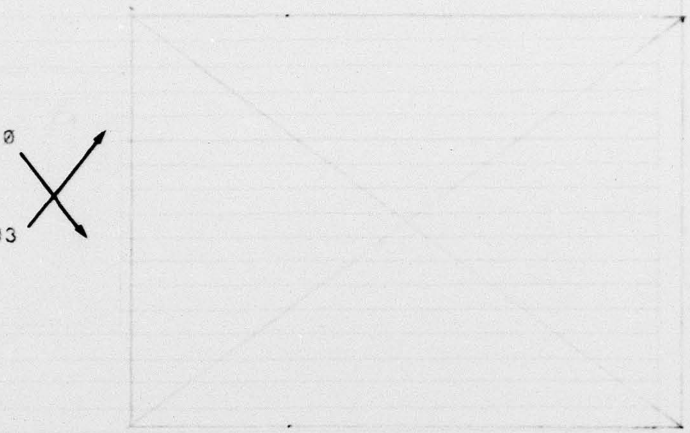


Figure 24. Data With Software FFT

```
OUTPUT ? X
FREQUENCY= +00005
+

OUTPUT ? Y
FREQUENCY= +00008
+

OUTPUT ?
```

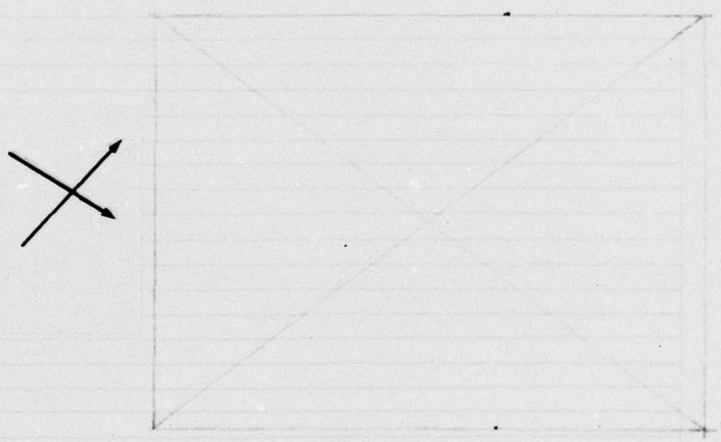


Figure 25. Data With Software FFT

TOP

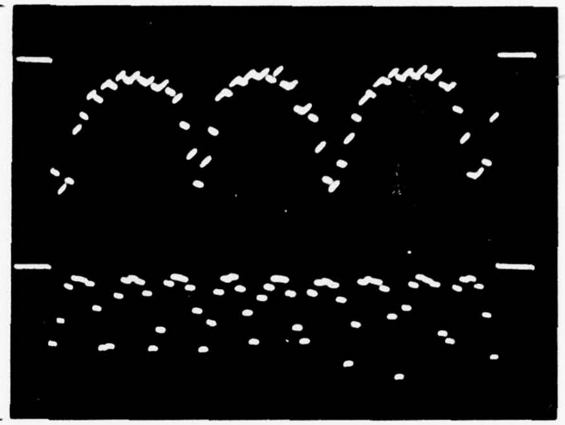


FIGURE 24. DATA WITH SOFTWARE FFT

S/S

TOP

FIGURE 25. DATA WITH SOFTWARE FFT

S/S

AFAL-TR-77-203
FIG- 24 & 25

```
OUTPUT ? X
FREQUENCY= +00006
+

OUTPUT ? YY
FREQUENCY= -00008
-
```

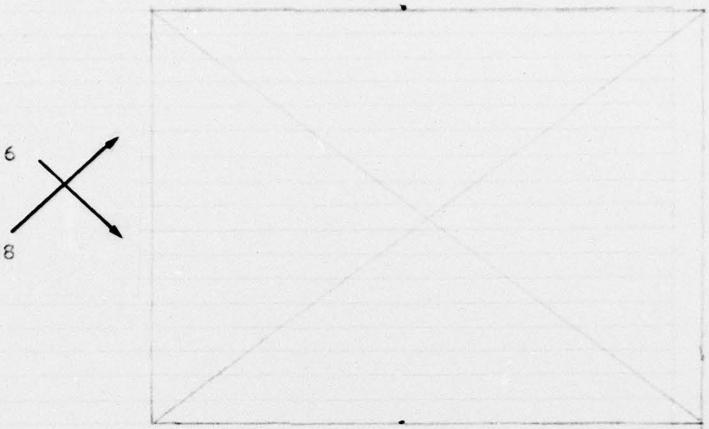


Figure 26. Data With Software FFT

```
OUTPUT ? X
FREQUENCY= +00008
+

OUTPUT ? Y
FREQUENCY= -00006
-

OUTPUT ?
```

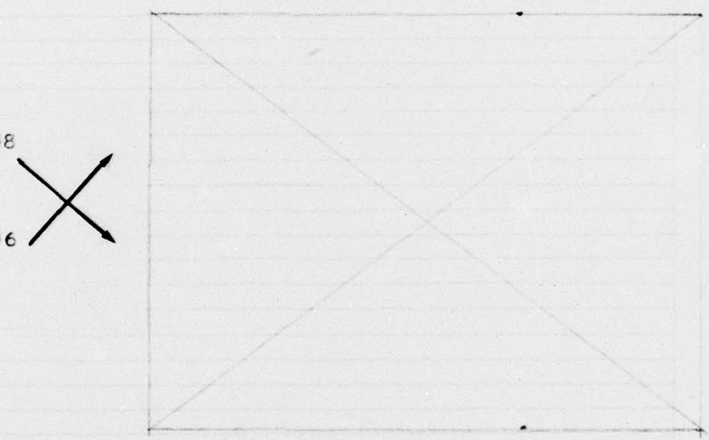


Figure 27. Data With Software FFT

TOP

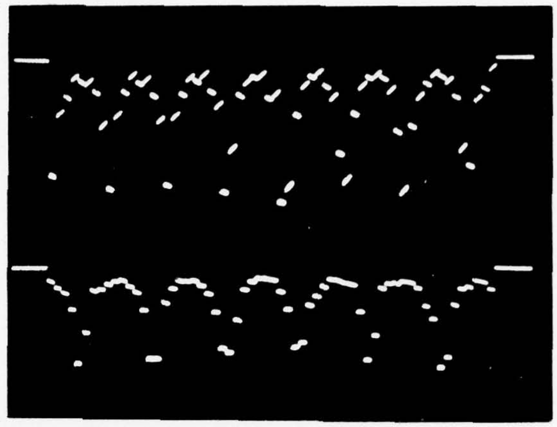


FIGURE 26. DATA WITH SOFTWARE FFT 5/5

TOP

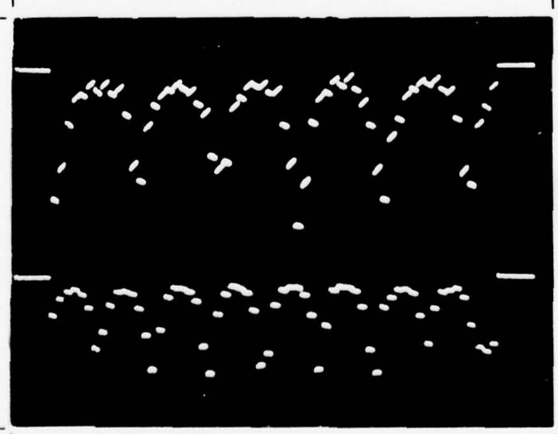


FIGURE 27 DATA WITH SOFTWARE FFT 5/5

AFAL-TR-77-203
FIG-26+27
PAGE-44

```
OUTPUT ? X
FREQUENCY= +00002
+

OUTPUT ? Y
FREQUENCY= -00010
-

OUTPUT ?
```

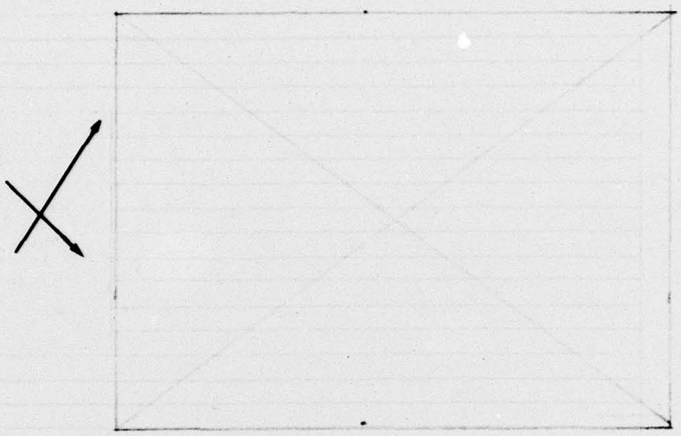


Figure 28. Data With Software FFT

```
LISTED ? Y

NO.# DATA AVERAGES , 1

OUTPUT ? Y

X-TOT SCAN DISTANCE ? , 1000

Y-TOT SCAN DISTANCE ? , 300

X-INCREMENT ? , 200

Y-INCREMENT ? , 100

   X          Y         FREQ               LIST

00200      00000       LOW      226,001,001,001,005,001,002,001,
                                  001,001,001,000,004,000,001,
00400      00000       0002      122,025,002,000,002,001,002,000,
                                  001,000,001,000,004,000,001,
00600      00000       0007      065,009,010,000,001,001,026,009,
                                  001,000,002,001,001,001,000,
00800      00000       0008      065,001,002,001,001,000,002,009,
                                  001,001,002,000,001,000,000,
01000      00000       0007      050,001,001,004,001,001,005,004,
                                  004,000,001,001,001,000,004,
00000      00100       LOW      200,004,001,004,001,001,002,000,
                                  000,001,001,000,005,000,000,
00200      00100       LOW      197,000,001,001,002,000,001,001,
                                  004,000,002,001,004,000,001,
00400      00100       0002      170,025,001,000,002,001,002,000,
                                  001,001,005,000,001,000,001,
00600      00100       0007      050,001,001,004,001,009,037,000,
                                  005,000,000,001,001,000,001,
00800      00100       0005      065,001,005,001,017,001,005,001,
                                  005,000,002,001,001,001,001,
01000      00100       0006      050,004,002,001,002,009,005,004,
                                  005,001,005,000,005,000,001,
00000      00200       LOW      122,002,002,001,002,001,002,001,
                                  004,002,001,000,004,000,001,
00200      00200       LOW      170,005,001,001,002,001,000,001,
                                  005,002,004,001,001,000,001,
00400      00200       LOW      170,004,001,000,002,001,002,001,
                                  001,000,002,000,000,000,001,
00600      00200       0005      085,004,001,001,017,016,002,001,
                                  002,000,005,000,001,001,000,
00800      00200       0006      082,001,005,000,005,025,001,000,
                                  005,001,005,000,000,001,001,
01000      00200       0007      082,001,002,004,001,000,009,001,
                                  004,001,000,004,004,000,001,
00000      00300       0011      082,004,005,000,001,001,001,001,
                                  001,000,005,000,001,001,000,
```

Figure 29. Finalized Data Run. Sample

Figure 30: a-r gives a comparison between the data incident on the detector and the data plots from the exit lines of the scanning detector, monitored on an oscilloscope. The top line of each plot is a detector scan in the x-direction and the bottom plot is a detector scan in the y-direction. It is left to the reader to interpret the results.

TOP

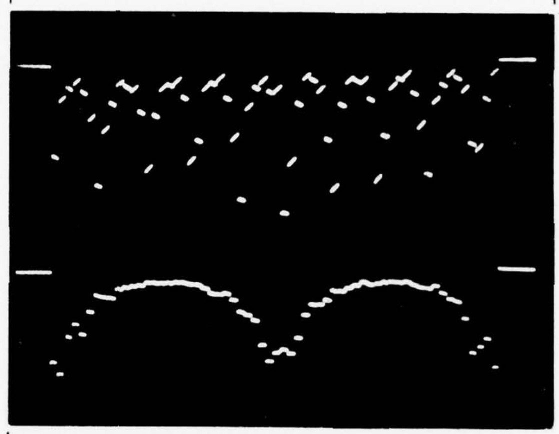


FIGURE 28. DATA WITH SOFTWARE FFT 5/5

AFAL-TR-77-203
FIG-28
PAGE-45

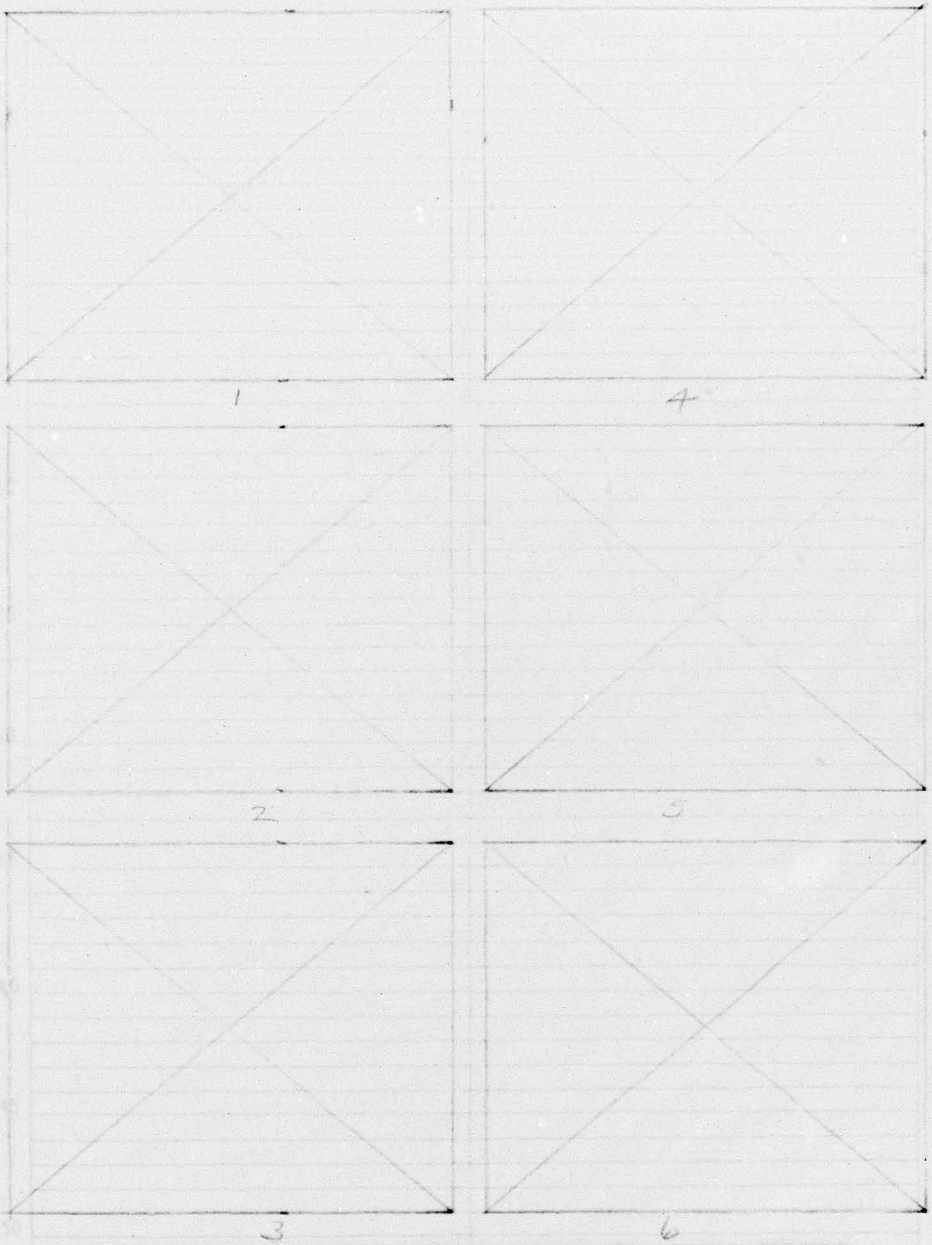


Figure 30 (a-c). Real Data With Different Specklegram Outputs

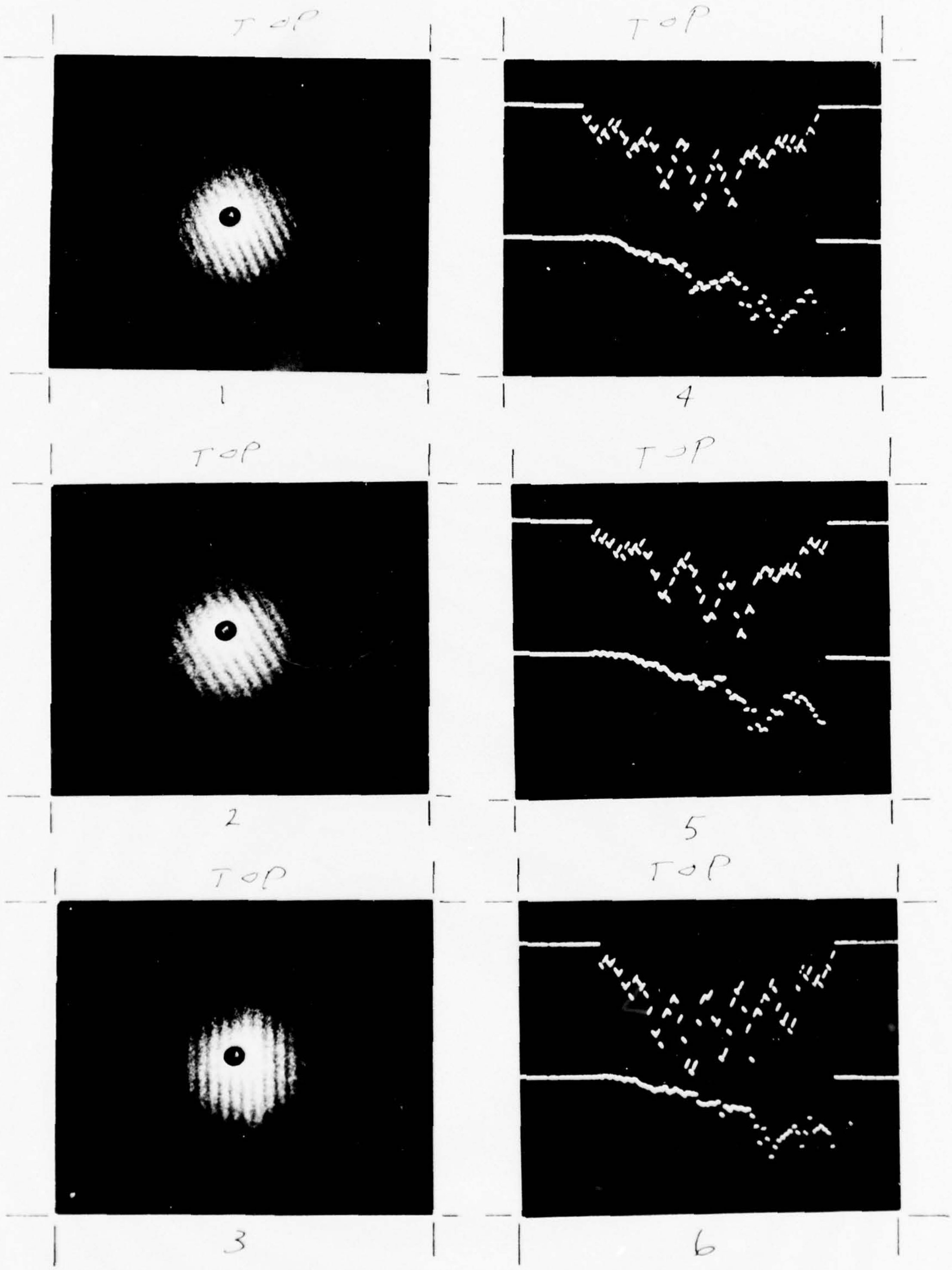


FIGURE 30. a - c

ALL 5/5

AFAL-TR-77-203

FIG- 30.a-c

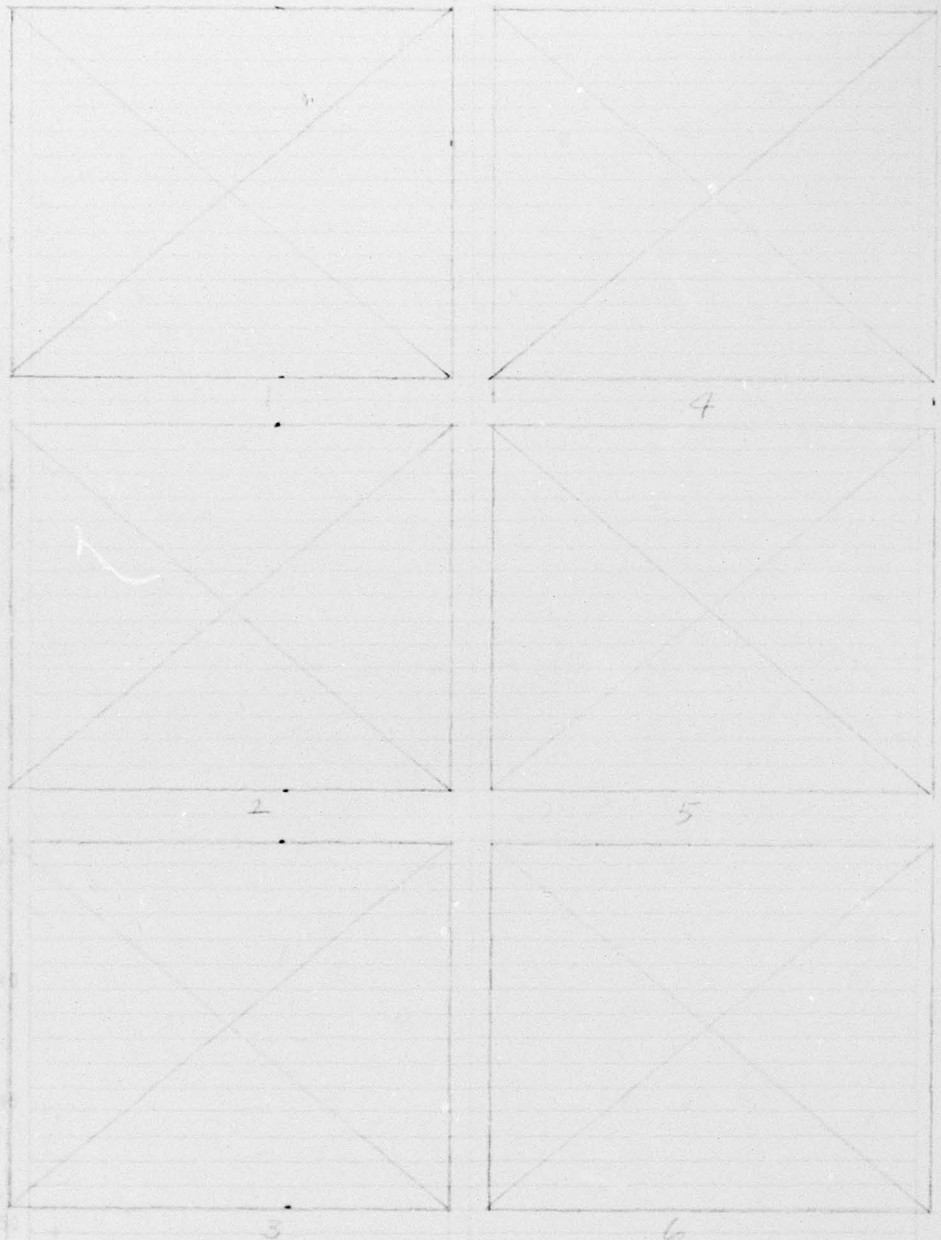


Figure 30 (d-f). Real Data With Different Specklegram Outputs

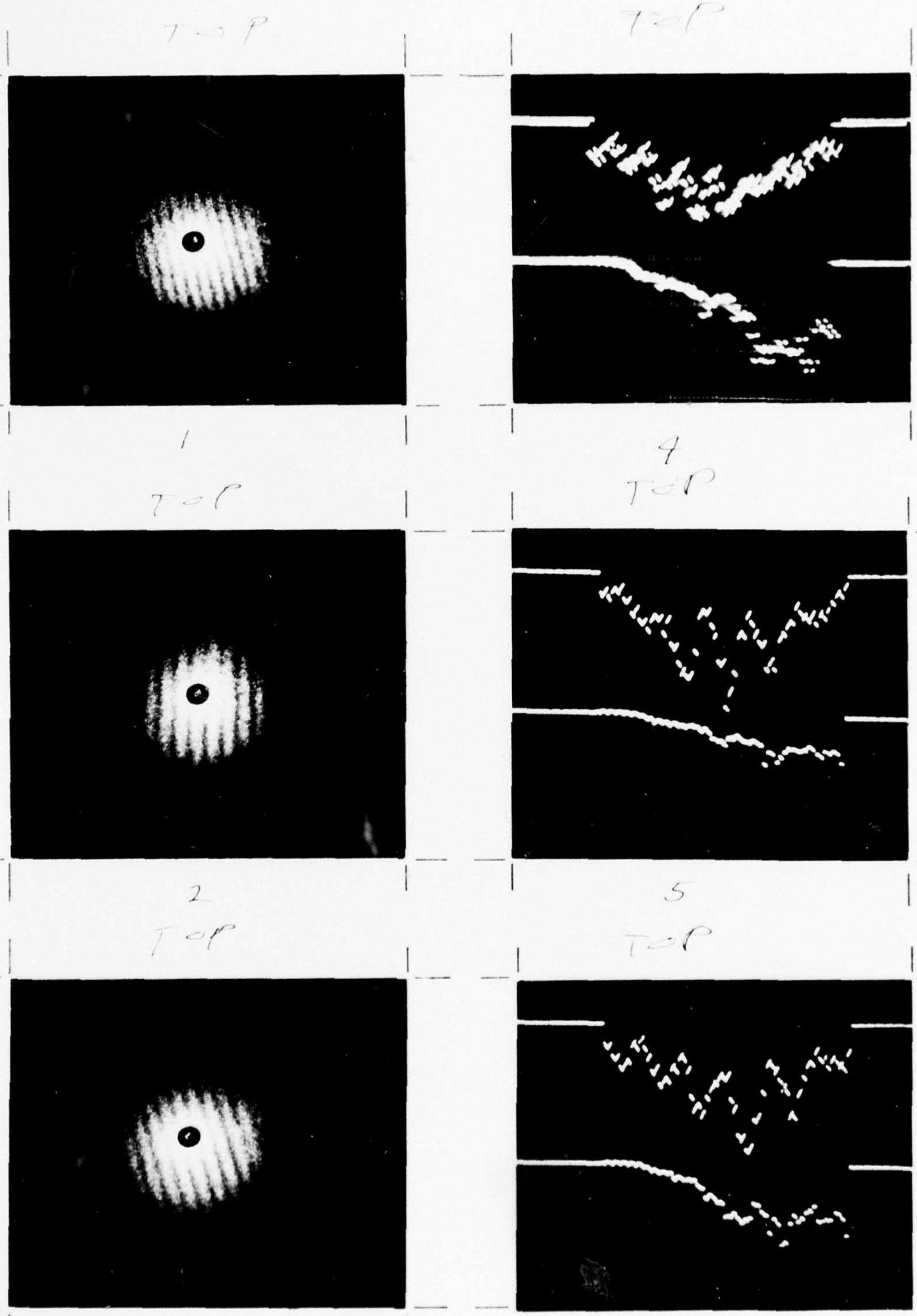


FIGURE 30. d - f

ALL 5/5
AFHL-TR-77-203
FIG- 30. d-f
PAGE - 49

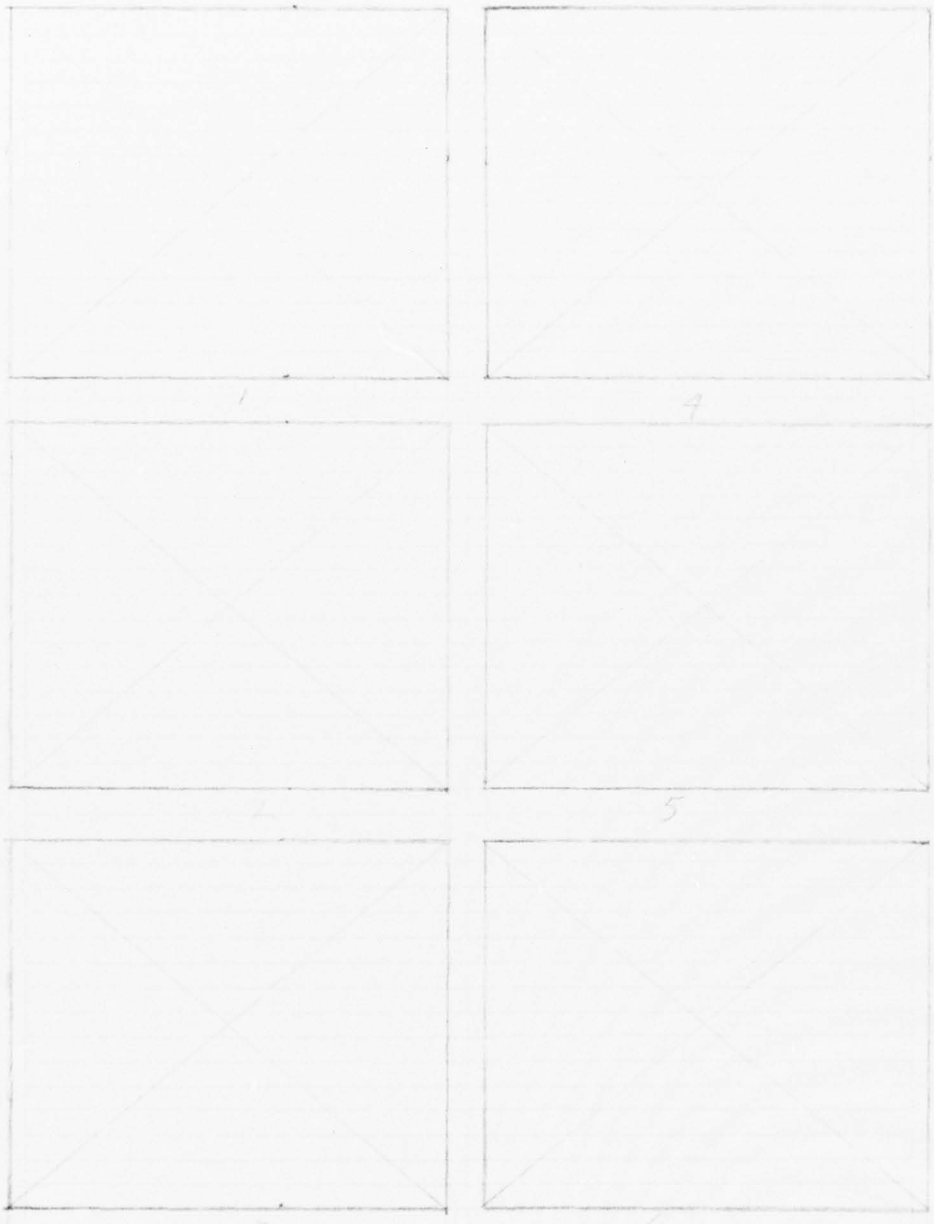


Figure 30 (g-i). Real Data With Different Specklegram Outputs

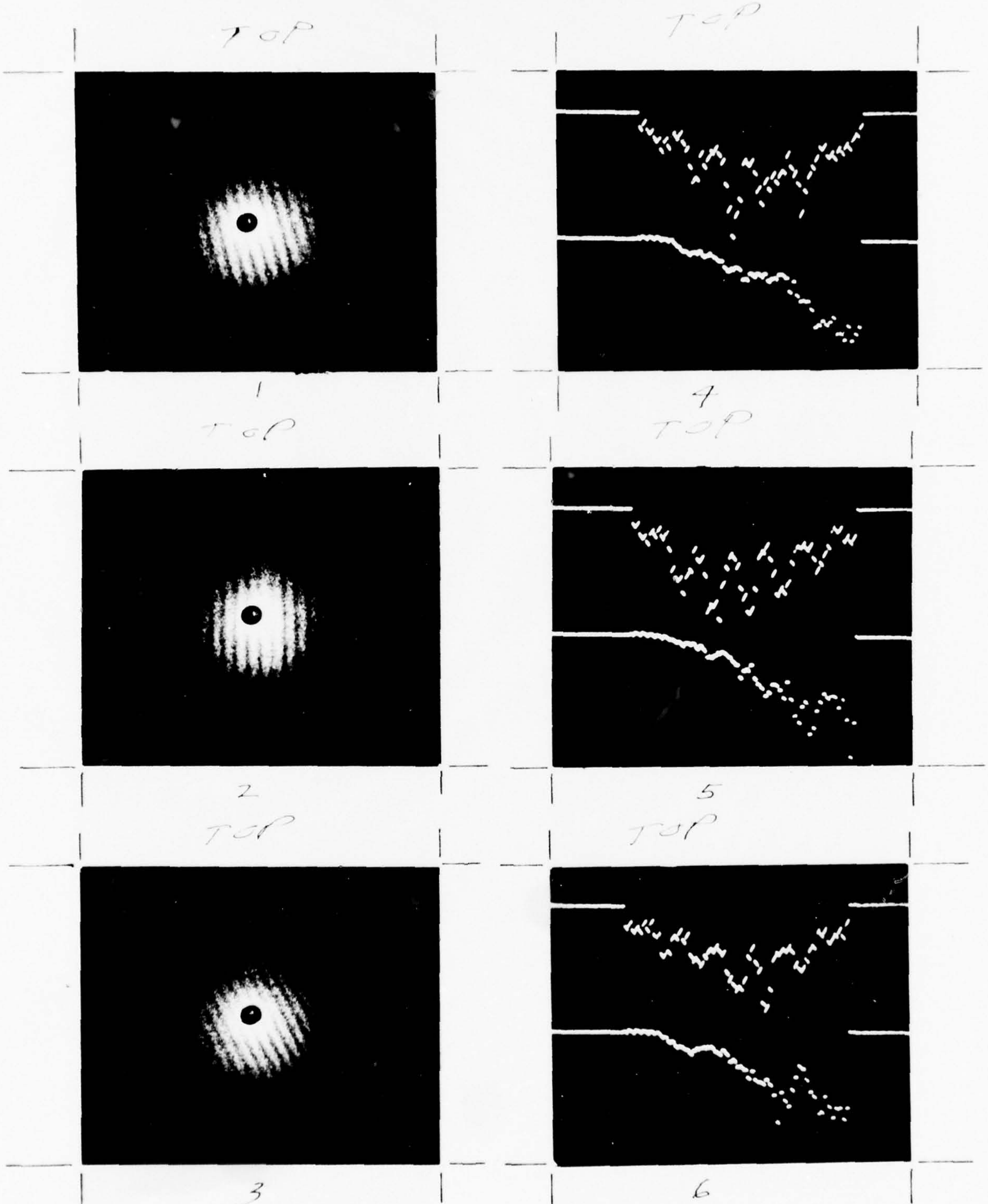


FIGURE 30. g - i

ALL S/S
AFAL-TR-77-203
FIG-30, g-i
PAGE-50

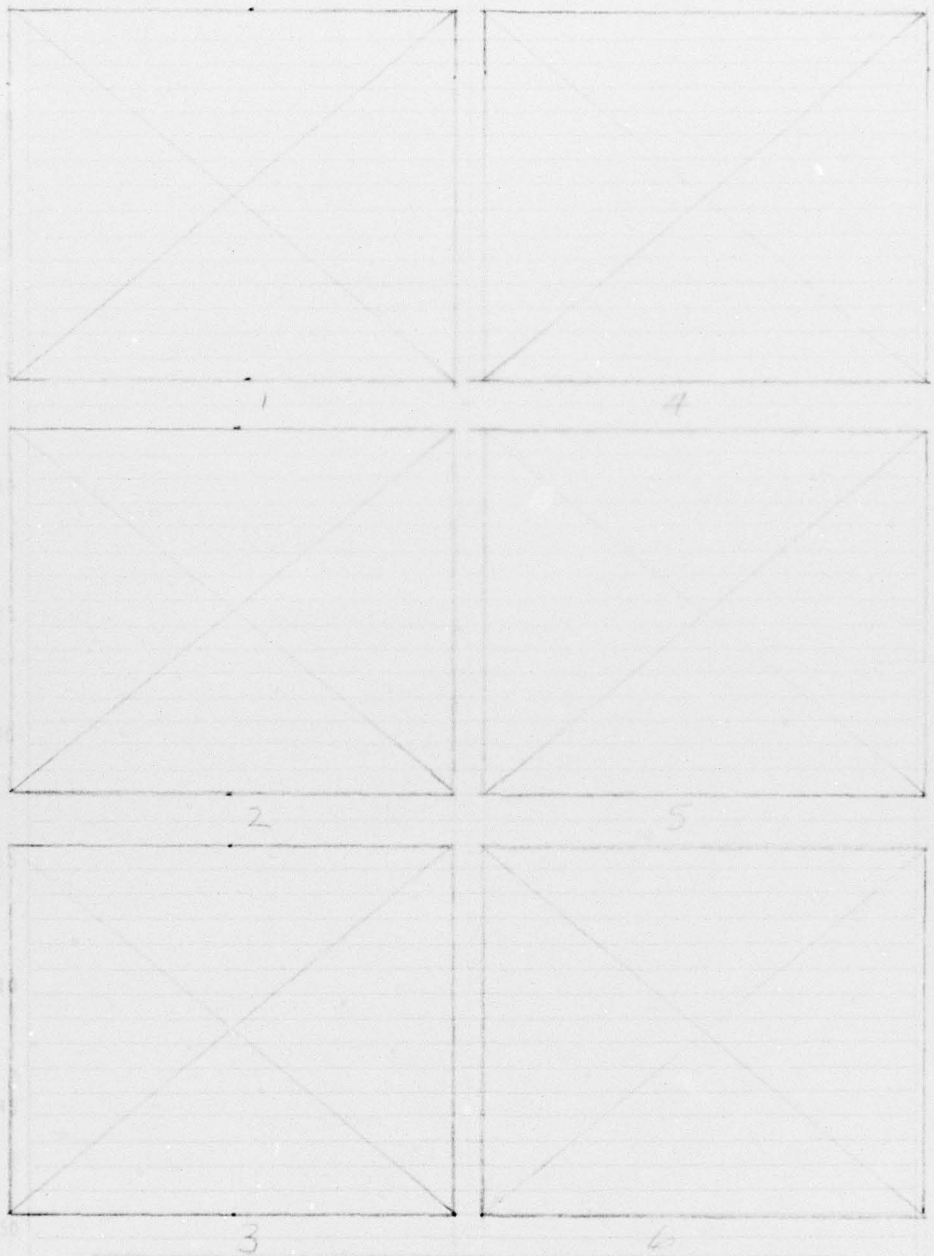


Figure 30 (j-1). Real Data With Different Specklegram Outputs

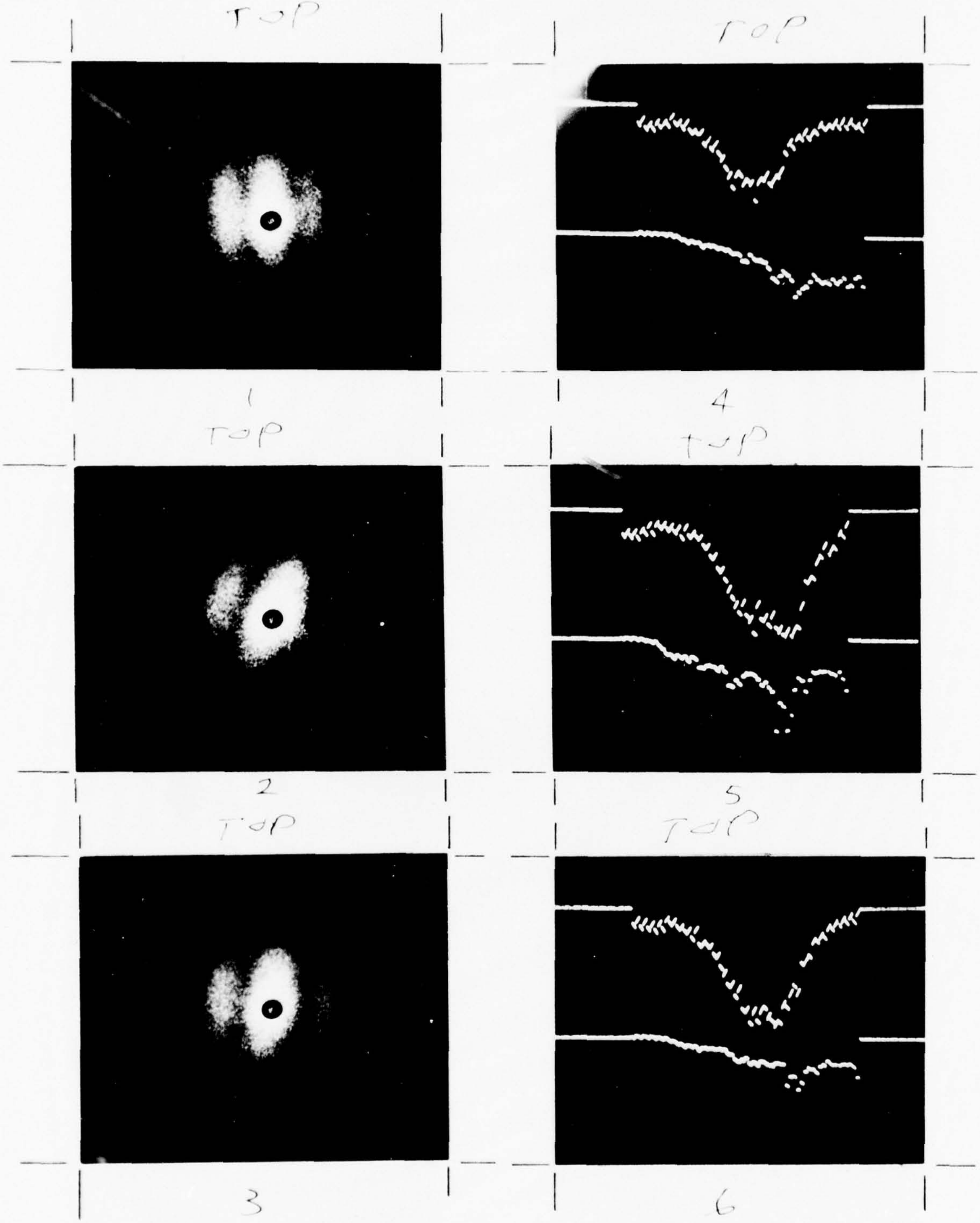


FIGURE 30. j - 1

ALL 5/5

AFAL-TR-77-203

FIG- 30. J-1

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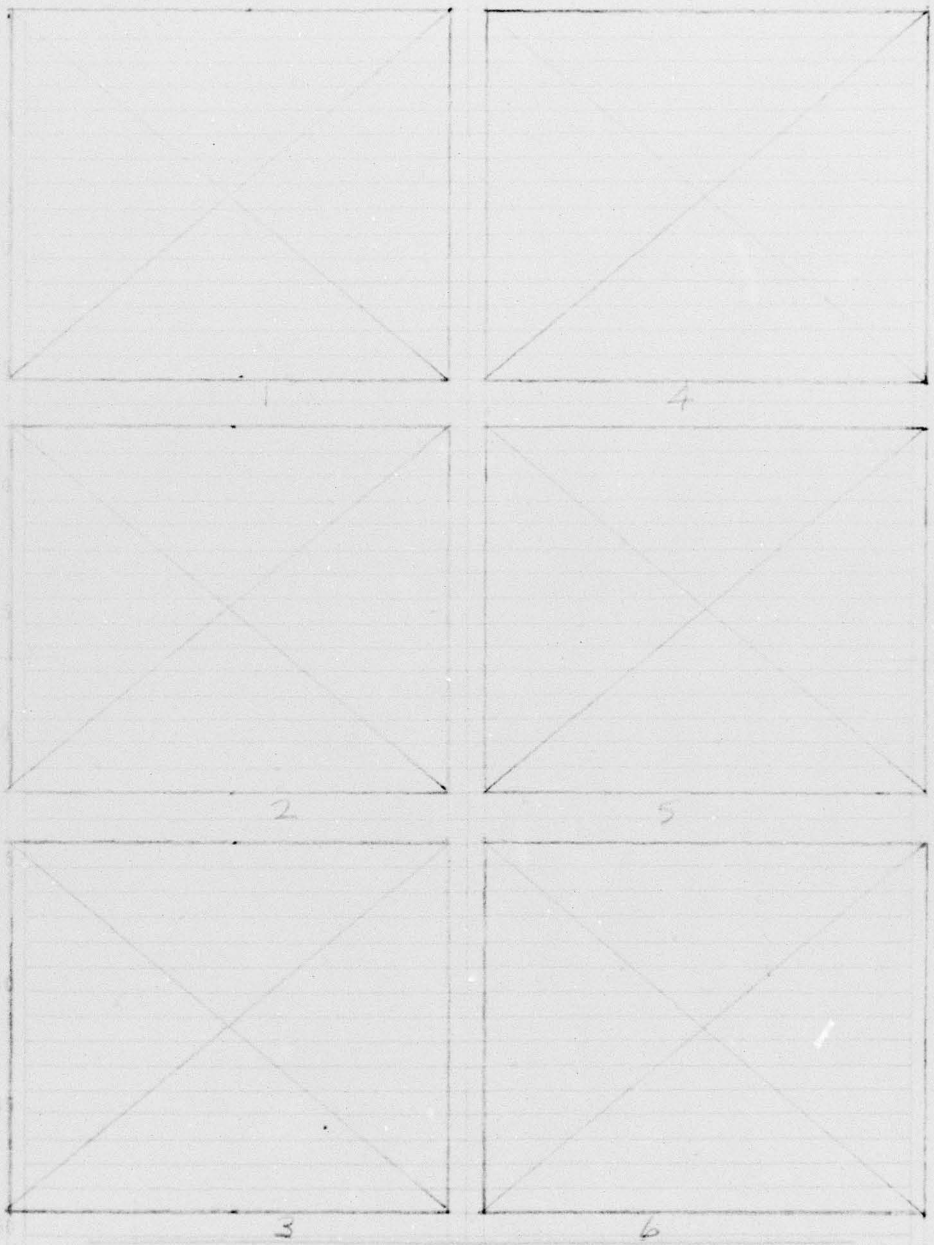


Figure 30 (m-o). Real Data With Different Specklegram Outputs

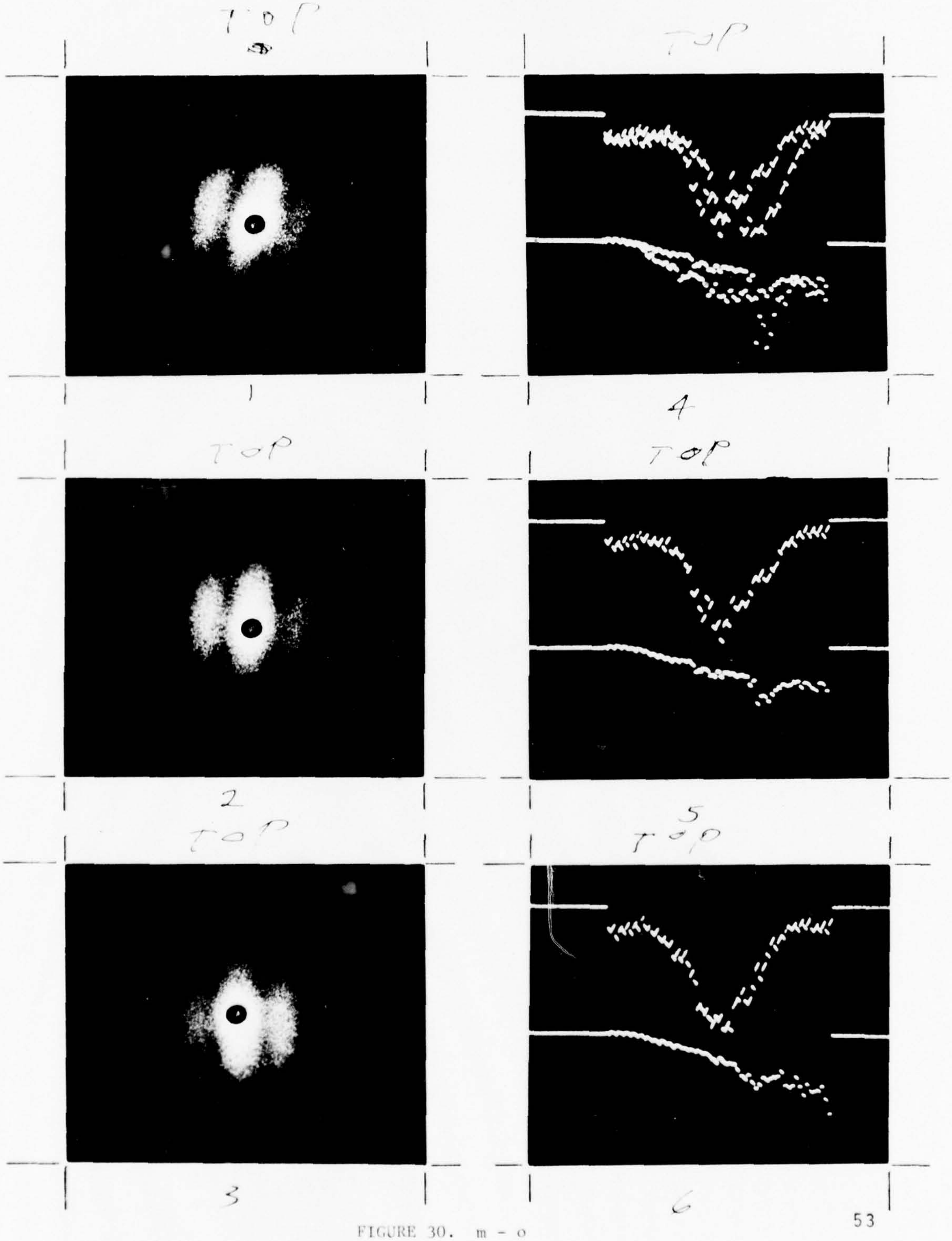


FIGURE 30. m - o

ALL S/S
AFAL-TR-77-203
FIG-30. m-o

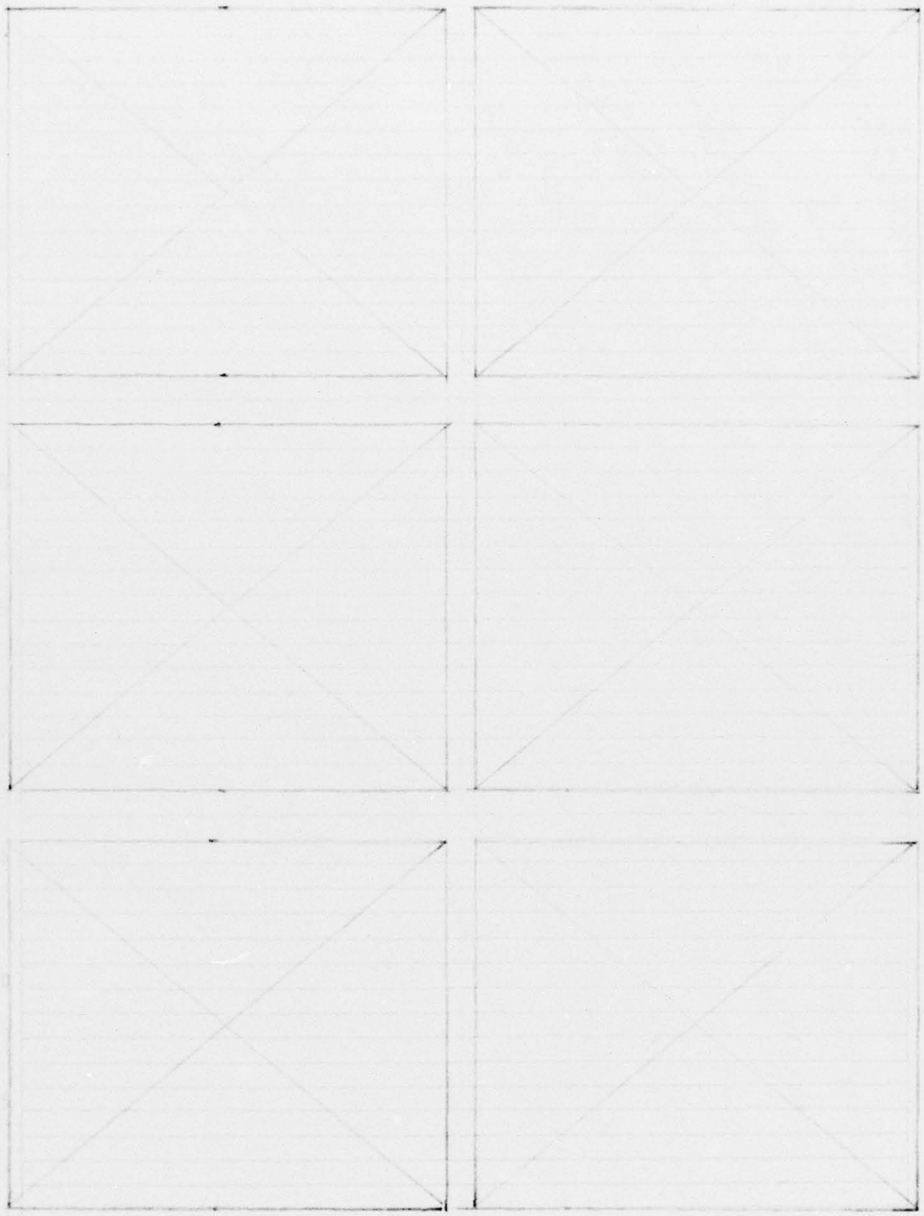


Figure 30 (p-r). Real Data With Different Specklegram Outputs

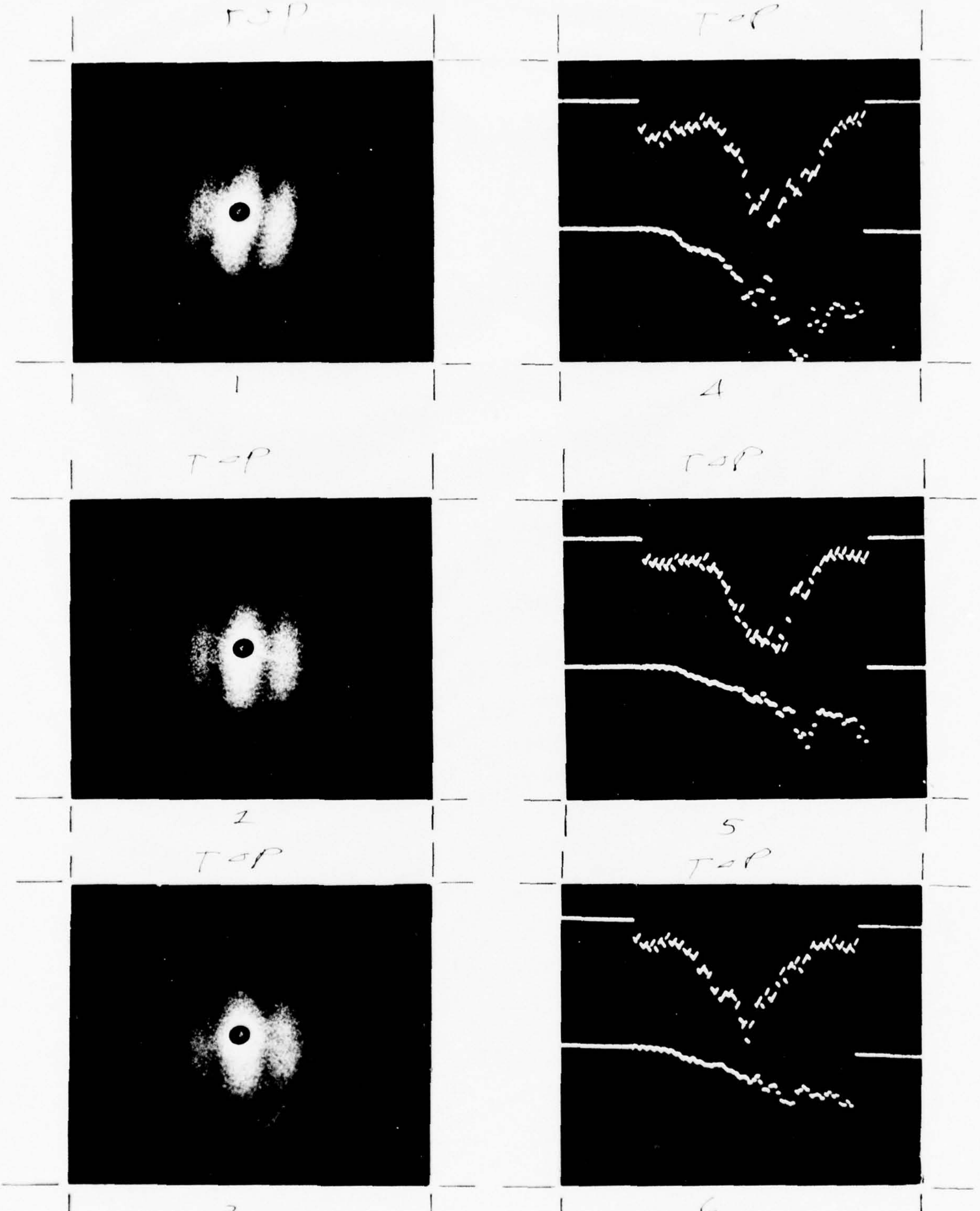


FIGURE 30. p - r

ALL 5/5
AFAL-TR-77-205
FIG-30 p-r
Page 53

SECTION VII

RESULTS

The results, although they did not meet the original requirements, produced some meaningful information as well as some aid toward development of a system to solve some of the problems of specklegram readout for the Air Force Flight Dynamics Laboratory.

The discussion that follows in this section pertains only to the system as it exists in its present state of development, directing itself in a time ordered fashion from the program beginning to now.

Much time was spent at the start in generating the correct electronics control signals, through the specially built logic circuitry, for activating the x-y stepping stage and the two dimensional detector array. Many capacitor and resistor changes were experimentally adjusted to allow the proper amplitude and pulse widths of the driving pulses required to operate these peripheral units optimumly.

Almost fifty hours of machine shop time was required to build the hardware to integrate much of the equipment. For instance, a specklegram holder had to be built for mounting to the x-y stage, a base was constructed to mount the x-y stage to the optical bench, a base was built for mounting the detector, and some special hardware was constructed for rack mounting the electrical circuitry and labeling the faceplate.

The system was then assembled and checked out in its final form as satisfactory and operable.

The software required most of the time from this point on. Each subroutine discussed in the software section of this report was written and rewritten until a final workable program was achieved. The data analysis section of the software program was written in two different forms: 1.) peak detection, 2.) Fast Fourier Transform. Essentially all the software for the peak detection was thrown out after it was determined to be inadequate for data analysis. Nearly all of the software progressions for both methods will be available at the contract close-out time.

SECTION VIII

CONCLUSIONS

In this section, I would like to discuss the present capability of the final system and also interject some possible solutions toward establishing a more accurate and feasible system for carrying out the initial objectives laid out for this project.

It appears that most of the objectives such as data analysis speed, automatic data input with .001-inch accuracy, and fringe angle and spacing determined by nonmechanical means, have been achieved with relatively few problems. It has been demonstrated that: 1.) a data analysis rate of 1-2 Hz is feasible in the existing software system; 2.) a .001-inch accuracy of stepping positions can be achieved under computer control at the above data analysis rate; and 3.) the detector shceme of two orthogonal linear arrays allows for the determination of angle and displacement completely independent of the fringe orientation on the detectors.

After completion of the software preliminaries and a checkout of the FFT portion of the computer program, some of the specklegram data furnished by Flight Dynamics Laboratory, was introduced for initial tests. During the testing period, various optical configuration changes were made such as varying the size of the readout laser beam and changing the image size of the specklegram fringes on the detector faces, which compensate for noise and detector optimization respectively. It was found that a beam size of approximately .25 mm was optimum to give maximum fringe contrast yet not cause too high a noise level due to large secondary speckle. It was also determined that an image size about 1-1/4 times the detector length utilized the detectors to their fullest, maintaining the best ratio between number of detectors per fringe and number of fringes per detector. For example, if 15 fringes were present across the complete halo, then approximately 12 fringes would be imaged across the 64 detector elements; thus there would be 5-1/3 detectors per fringe. For a low number of fringes (5) there would be 4 fringes projected onto the detectors thus 16 detectors per fringe.

The best results that could be obtained from the 15 fringe case would be to the nearest fourth of a fringe but since noise and other experimental errors are present, only about 1 fringe resolution can be obtained. For the case of 5 fringes in the projected halo, about a quarter of a fringe resolution is possible. The system, as it exists in its present state, can analyze data at a 2-3 point per second rate with a very low resolution accuracy.

Some thought has gone into methods of improving the system resolution which appears to be the main problem at the present time, without any major change in the overall system configuration.

The first thought which came to mind was to try to reduce the secondary speckle noise without changing the fringe resolution of the output data. Two methods of in-house experimentation are going to be performed for solving this problem. The first will be to slightly misdirect, at a high fringe rate, the readout laser beam in an optical system where the image plane is held stationary. This could be performed with a motor driven rotating wedge. The second method would be to project the output fringe pattern onto a liquid crystal dynamic diffuser, which acts as a random phase medium that is electrically controlled. A surface of this type would tend to shift the secondary speckle a small amount in a random fashion at a rapid rate. In both the above mentioned methods, the secondary speckle noise would be minimized by taking several detector scan data samples and averaging them digitally over a short period of time. This process could be done with a small amount of modification to the existing system.

Another way of analyzing the specklegram data that will be considered, uses the optical fourier transform. By using either the rotating wedge or the diffuser as a noise reduction scheme, an optical system consisting of a laser, specklegram, diffuser, fourier transform lens, D.C. Block, and appropriate detector could perform the equivalency of the digital fast fourier transform operation, in an optical train with an essentially zero time frame, thus eliminating one large time consuming aspect of the present method.

All of the above techniques are being considered in-house under project 2001-02-42 of AFAL/DHO-2. If any of the methods prove feasible then further experimentation could be performed by Flight Dynamics Laboratory approval.

APPENDIX I

A FEASIBILITY STUDY OF AUTOMATIC FRINGE COUNTING TECHNIQUES

13 November 1973

By C. Richard Lane

BACKGROUND:

As a result of structural problems associated with the C-5 aircraft, Dr. Lovelace has asked that all laboratories reflect on possible solutions to the problem of monitoring the structural integrity of critical areas on the aircraft. Based on their past experience in the area of non-destructive testing of aircraft structures, Flight Dynamic Laboratory organized an approach to provide such a monitoring system in cooperation with ARL, and AFAL. This work is presently being done under AFFDL work unit 1467-02-12 with Mr. Gene Maddux and Dr. Frank Adams as principal investigators.

The initial approach taken by FDL utilizes the recording of a double exposure speckled image of the area of the structure being monitored, where some strain is introduced between exposures. This double exposed image is then processed to make a transparency. Upon illumination by a small laser beam a set of fringes are projected which represent the correlation of the speckles at that location on the image.

These fringes can be related to the surface motion that took place between the two exposures, the structural integrity at that point.

Although this technique is limited with respect to the size, type, and depth of the flows that it can detect, it provides a good first step and is essential to more complex techniques that have potential of overcoming these limitations.

For each C-5 aircraft a large number of these specklegrams would be required (5,000 - 10,000 if one specklegram were made for each installed wing fastener) and a large number (100 - 1000) of points per specklegram would need to be analyzed. It is, thus, obvious that an automated system is required that will map the surface motion with each specklegram area.

OBJECTIVE:

The objective of the initial in-house effort within AFAL was to investigate techniques of determining the spacing and direction of a projected sample fringe pattern. This investigation included the demonstration of the techniques on a sample specklegram provided by AFFDL.

APPROACH:

As a result of past experience with similar type problems in the area of optical processing and the availability of equipment within AFAL two approaches to the problem were taken. Both approaches required that the fringe pattern be read-in automatically by one of three ways:

a. Scanning point detectors.

b. Electrically scanned linear diode arrays.

c. Electrically scanned 2-dimensional image, dissector tube.

Once the fringe information was detected, two approaches were considered to analyze the fringes and indicate the spacing and direction. The two approaches were:

a. Store the information in a memory unit, then perform a 2-dimensional fast fourier transform (FFT) to determine the spatial frequency component in both magnitude and angle. The FFT was chosen over optical transforming due to the lack of spatial coherence in the speckled fringe pattern.

b. As the information is read-in, perform a peak detection operation and average the peak spacing for scans in two directions. By means of a simple arithmetic operation the maximum spacing and direction were then determined.

Evaluation of both approaches were carried out on the sample provided.

DISCUSSION OF THE 3 DEMONSTRATION TECHNIQUES:

Two of the three demonstrations to be discussed now were done only minimally and were investigated only to the extent of being considered as a possible solution to the fringe counting problem. Although all three demonstrations were capable of providing a solution to the problem, only the third was experimented with to the desired extent. It will also be seen that the 3 demonstrations were similar enough in theory that it can be assumed that if one experiment works then all three, with proper implementation, can serve as a solution. All three techniques have been discussed and demonstrated to: Mr. G. Maddux and Dr. Frank Adams of the Flight Dynamics Laboratory.

1) On 6 August 1973 a sales representative from Tektronix Incorporated accompanied to our lab, a processing oscilloscope being considered for purchase under project 2001-04-10. The sales representative set up the processing system in the lab which consisted of a Model 7704A

oscilloscope with standard scope plug-ins, a Model 7001 Processor, a PDP 11-05, 16K core mini-computer, a CRT display terminal, and a rapid read-write tape punch. The self-scanning detector array was introduced into the system through the oscilloscope inputs. The array, scanning its 512 elements at a 200 Hz rate, was synchronized to the scope such that all 512 elements were displayed on the scope screen in one sweep (5msec). The processor portion of the system then digitizes the data displayed on the scope screen and sends it to the PDP 11 computer along with a command of which software program to implement on the data. The resulting answer can then be displayed by a curve trace on the scope screen or CRT screen of the terminal.

Due to a lack of time and the limited software programs available by the sales representative, only a fast fourier transform program was used to attack the fringe counting problem. The fringes to be measured were imaged on the reticon array and displayed on the scope. By a stroke of luck, the FFT program being demonstrated needed 512 digitized points to perform the transform, exactly the number of detectors in the scanning array. The signal being displayed is now averaged over several scans of the array and then the FFT program is called up and performed on the averaged signal and the result displayed with 512 points on the oscilloscope screen.

Two sets of fringes were experimented upon during the demonstration: An equally spaced set of .05 inch fringes; and a set of fringes generated from a specklegram.

a. Figure 2a shows the fringes imaged on the reticon and averaged 1024 times to eliminate unwanted noise. From the figure there are 21-22 fringes across the 512 elements of data, and multiplying the number of fringes by 200 Hz (the scan rate of the detector), gives the frequency that the computer actually sees.

(1) 21 x 200 = 4200 Hz = 4.2 KHz

(2) 22 x 200 = 4400 Hz = 4.4 KHz

Figure 2b illustrates the fast fourier transform of the signal of Figure 2a, and the strong peak (arrow) is printed out as 4.3 KHz, a reasonable result.

b. Figure 3a is a scope trace of a sample specklegram from FDL, one trace a single sweep and the other a trace averaged 512 times. These two traces illustrate the noise reduction capability of averaging a signal over several traces. This noise reduction factor could prove very necessary if other methods of fringe counting other than FFT, is implemented. The FFT displayed in Figure 3b shows two significant peaks of data relating to the fringe spacing. The peak indicated by the red arrow is a 200 Hz frequency spike representative of the scan rate of the reticon array. This frequency spike is a consequence of the input fringes not filling the entire aperture of the array, thus the synchronizing pulses from the clocking circuit of the array are prominent. If approximately the first 30 registers of the data in Figure 3b are set to zero (200 Hz spike), the strongest frequency then becomes the second spike and this frequency value is printed in Figure 3c with a 50mv to 20 mv vertical scale change. By examination of Figure 3a it should be obvious that 4.2 MHz represents the fringe frequency of major concern. As a simple conclusion, a software programming addition that cancels out the 200 Hz clocking rate would be incorporated and only the desired frequency peak would be predominate. By retransforming the result obtained in Figure 3c, it is seen that the same fringe spacking is preserved after cancellation of the 200 Hz peak (Figure 3d).

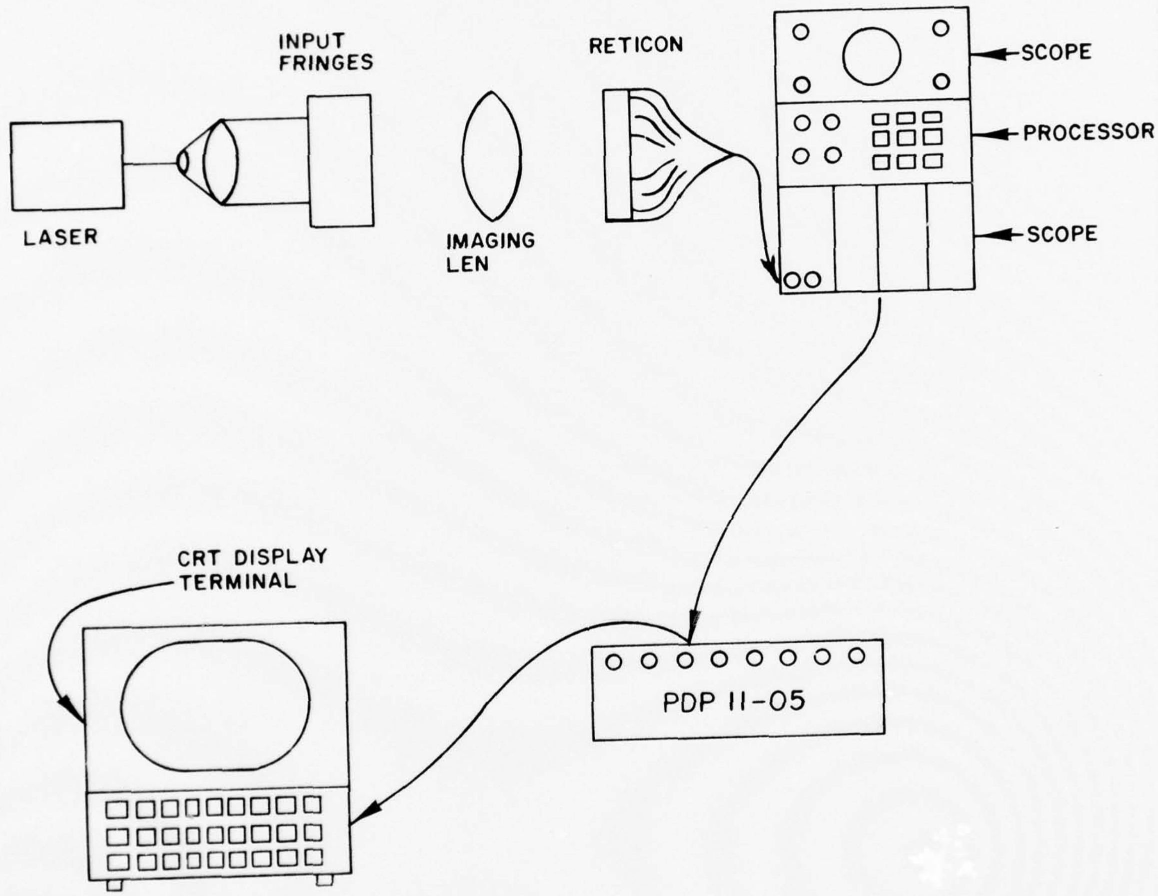

INPUT
FRINGES
RETICON
SCOPE
PROCESSOR
SCOPE
LASER
IMAGING
LEN
CRT DISPLAY
TERMINAL
PDP 11-05

Figure 1a

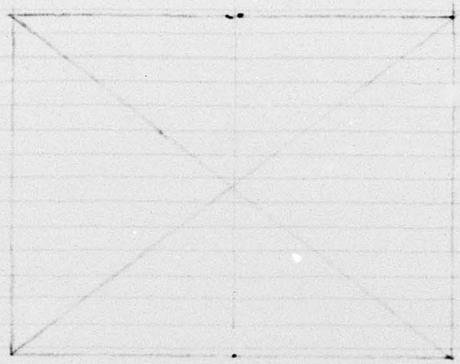


Figure 2a

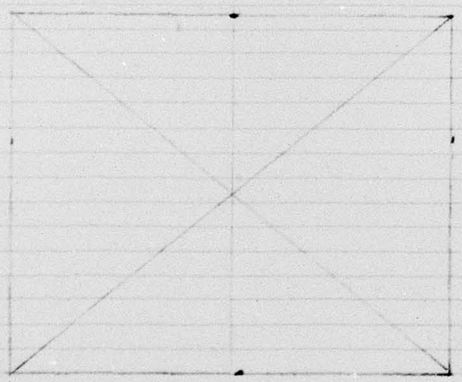


Figure 2b

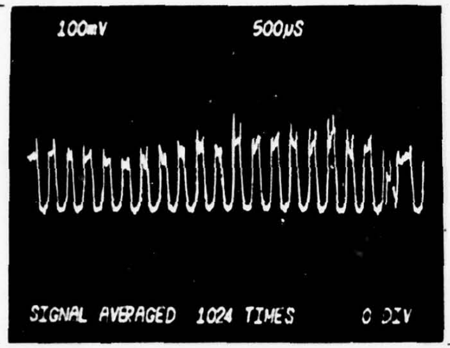


Figure 2a

5/5

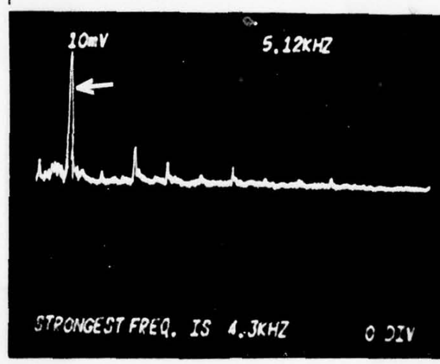


Figure 2b

5/5

AFAL-TR-77-203
FIG-2a+2b
PAGE-65

2) The second method of demonstration will be discussed only briefly since it is similar in procedure to the third demonstration with slightly more sophisticated equipment. Figure 1b shows the basic setup used for this demonstration. The primary difference between this procedure and the first demonstration procedure is that instead of calculating a fast fourier transform with a PDP 11 computer, a counting program was implemented. The program performs an adjacent register comparison to locate peak points and then checks the difference between these peak points. This approach is instrumented by two orthogonal scans across the fringe pattern with an electronically raster scanned image dissector tube. Essentially, the result is an x and y fringe spacing measurement of which an actual fringe spacing may be calculated along with a fringe angle displacement. This procedure will be discussed more thoroughly in the next demonstration. The sole purpose of this experiment was to indicate the feasibility of using an image disector tube for the fringe counting problem.

3) The demonstration to be discussed now utilized equipment already existing in the laboratory of AFAL/TEL and thus was readily available during a longer period of time required for a more thorough investigation. The equipment used and its configuration are illustrated in Figure 1c.

SYSTEM DESCRIPTION:

A laser is used to illuminate a set of fringes at the input plane and an imaging lens projects the fringes onto an x-y scanning aperture. The variable size aperture is scanned by two bi-directional variable speed D.C. motors which are manually started and stopped. The aperture sizes are configured such that the resolution of the system can vary from a small fraction of one fringe down to a single fringe or essentially no resolution. This aperture size variation can be used constructively to reduce noise in the system resulting in less software work and time for the computer to implement at a later stage in the processing. A digital

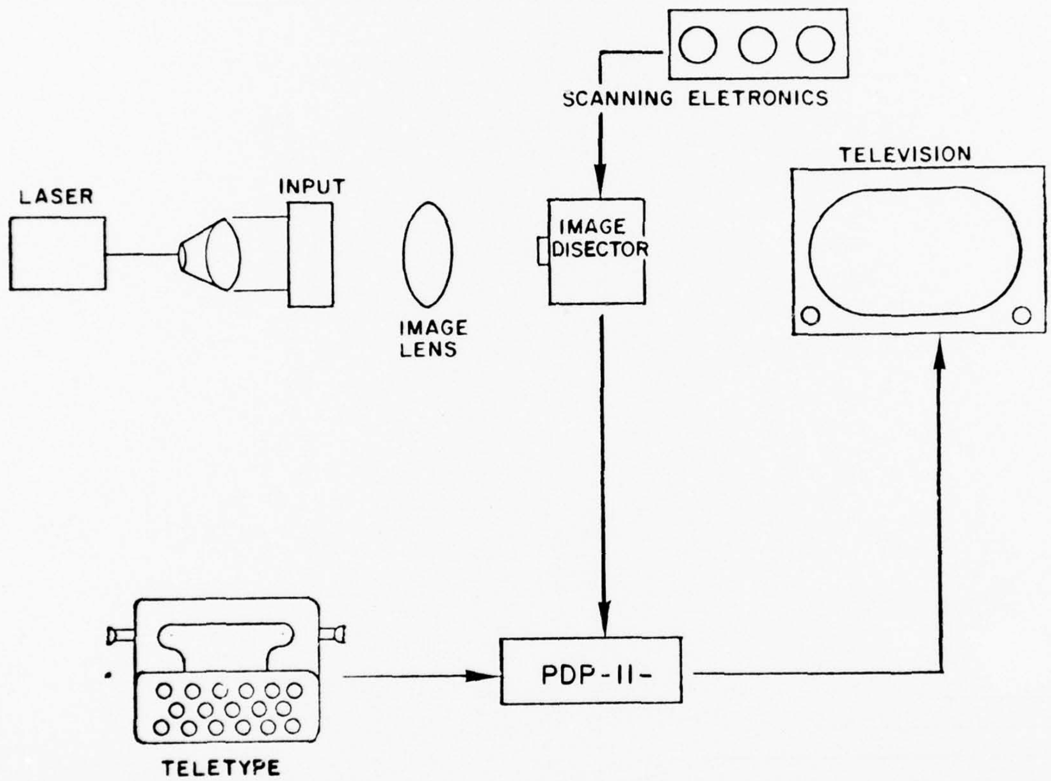

SCANNING ELETRONICS
TELEVISION
LASER
INPUT
IMAGE
DISECTOR
IMAGE
LENS
PDP-11-
TELETYPE

Figure 1b

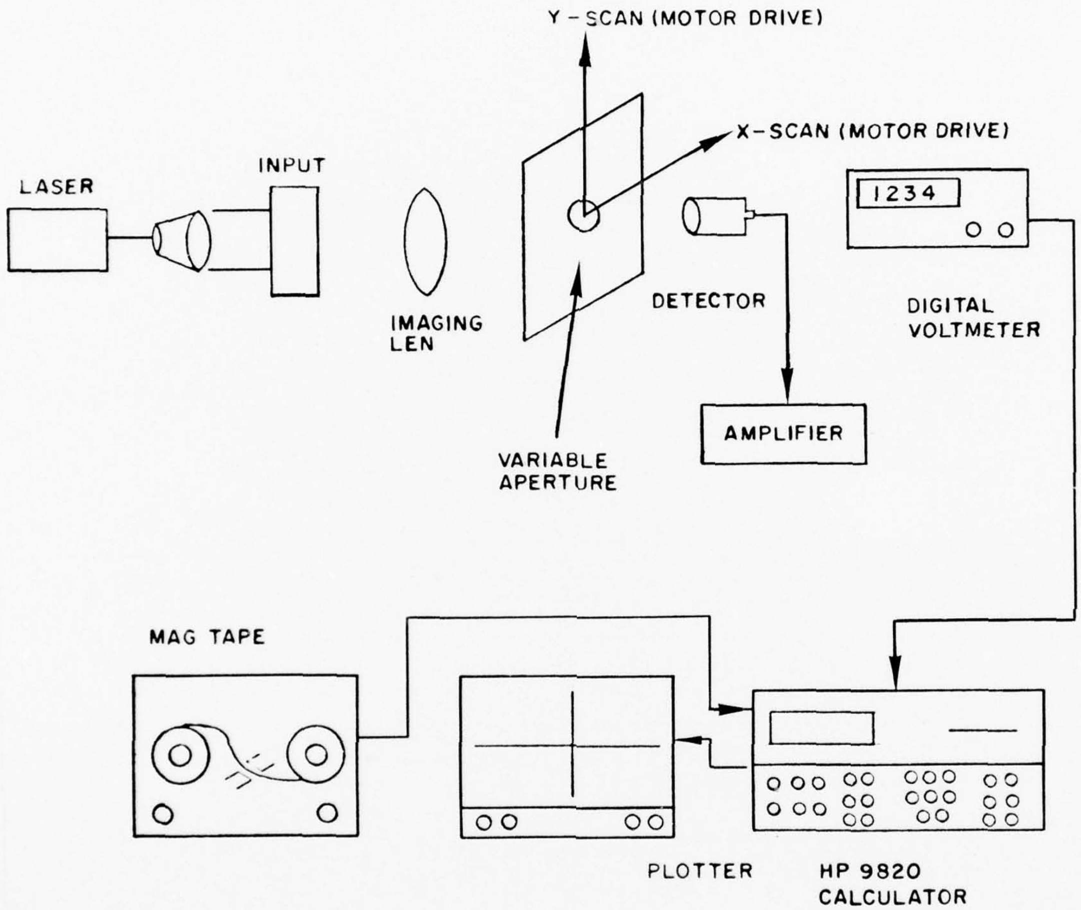

Y - SCAN (MOTOR DRIVE)
X-SCAN (MOTOR DRIVE)
LASER
INPUT
1234
IMAGING
LEN
DETECTOR
DIGITAL
VOLTMETER
AMPLIFIER
VARIABLE
APERTURE
MAG TAPE
PLOTTER
HP 9820
CALCULATOR

Figure 1c

voltmeter is used to pick up the intensity pattern of the fringes and also serves as an analog-to-digital converter that directly interfaces with the Model 9820 Hewlett Packard Calculator. The digital voltmeter and calculator combination is extremely slow for use as a data collector since it operates at a maximum data sampling rate of 3 samples per second. This fact rules out this type of system as a final product to solve the fringe counting problem, although it strongly demonstrates the feasibility of using a similar fringe counting technique with a data reading capability of approximately 4-5 magnitudes greater. A plotter can also be tied directly to the system giving a visual description of the fringe data that the calculator will process.

SAMPLE PROCEDURE:

A good method of examining the procedure used to count the fringes would be to look at Figure 4a, b, and c, which list the calculator program, in some detail.

The first step is to image the fringe pattern onto the scanning aperture plane and position the aperture in the y direction ready to scan across the complete fringe pattern.

By simultaneously running the program and starting the y direction scan (manually), the "reads data" portion of the program begins reading in the fringe information to the designated registers R0 - through R100. Following the 25 second data read in time, the program initializes step II which normalizes the data such that the minimum voltage register is zero and all other registers are shifted about the zero level. Section III in the program finds the register with maximum value and affixes this value to the scale setting needed for plotting the 100 data registers (IV) representing the fringe pattern. The fifth portion points out the data

FIGURE 4a.

```
Ø:
Ø→X;FXD Ø⊦
1:
Ø→RX; IF  (X+1→X)≤
249; JMP Ø⊦
2:
Ø→X⊦
3:                          I
RED 3,A,RX; IF  (X            READS DATA FROM DIGITAL VOLTMETER
+1→X)≤1ØØ; JMP  Ø⊦
4:
Ø→X;RX→B;Ø→C⊦
5:
IF RX≤B;RX→B;X→C
⊦
6:                         II   NORMALIZES THE DATA TO ZERO
IF (X+1→X)≤1ØØ;
JMP -1⊦
7:
Ø→X⊦
8:
RX-B→RX; IF  (X+1→
X)≤1ØØ; JMP Ø⊦
9:
Ø→X; JMP 9⊦
1Ø:
IF RX>R13Ø;RX→R1
3Ø⊦
11:                       III   SETS THE SCALE FOR THE PLOT
IF (X+1→X)≤1ØØ;
JMP -1⊦
12:
SCL Ø, 1ØØ,Ø,R13Ø
;Ø→X⊦
13:
PLT X,RX;IF  (X+1
→X)≤1ØØ; JMP Ø⊦          IV   PLOTS THE FRINGES
14:
PEN ;SPC 2⊦
15:
Ø→X;FXD Ø⊦
16:
IF RX>.5E-2;PRT
X; JMP 1⊦                  V   PRINTS THE WIDTH OF THE FRINGE
17:                                 PATTERN BY REGISTERS
IF (X+1→X)≤1ØØ;
JMP -1⊦
18:
SPC 2;PRT "THE PEAKS
ARE";PRT "AT
REGISTERS"⊦
19:
Ø→X⊦
2Ø:
IF RX≤1E-2;Ø→RX⊦          VI   SETS SMALL VALUES OF NOISE
21:                                 AMPLITUDE TO ZERO
IF 1X+1→X)≤1ØØ;
JMP -1⊦
```

FIGURE 4b.

```
22:
Ø→X; 15Ø→Y⊢
23:
IF R(X+1)>RX;X+1
→RY;IF  (X+1→X)≤1
ØØ; JMP Ø⊢
24:
IF X>99; JMP 4⊢
25:
IF R(X+1)≤RX;I⊢
(X+1→X)≤1ØØ; JMP
Ø⊢
26:
IF X>99;JMP 2⊢
27:
Y+1→Y; JMP -4⊢
```

VII — CALCULATES AND STORES THE RESISTERS WHERE PEAKS OCCUR

```
28:
Y→C; 15Ø→Y⊢
29:
PRT RY;IF (Y+1→Y
)≤C; JMP Ø⊢
```

VIII — PRINTS THE PEAK REGISTERS

```
3Ø:
Ø→R(C+1);SPC 3;
PRT "DISTANCE BE
TWEEN";PRT "FRIN
GES IN"⊢
31:
ENT "X-DIRECTION
?", B; IF B=1;
PRT "X-DIRECTION
 IS";JMP 2⊢
32:
PRT "Y-DIRECTION
 IS"⊢
```

IX → ASKS FOR DIRECTION OF SCAN

```
33:
2ØØ→C;151→Y⊢
34:
R(Y+1)-RY→RC;C+1
→C;Y+1→Y;IF R(C-
1)>.1;JMP Ø⊢
```

X — CALCULATES DIFFERENCE BETWEEN PEAKS

```
35:
C→A;2ØØ→C⊢
36:
IF RC≤3;JMP 3⊢
37:
IF (C+1→C)>A-2;
JMP 4⊢
38:
JMP -2⊢
39:
IF C=2ØØ;R(C+1)→
RC;JMP -2⊢
4Ø:
R(C-1)→RC;JMP -3
⊢
```

XI — IF SMALL PEAKS SHOW UP, THESE STEPS SET SMALL DIFFERENCES TO ADJACENT DIFFERENCE

```
41:
2ØØ→C⊢
```

FIGURE 4c.

```
42:
RC+R (C+1)→R(C-1)
⊦
43:
C+1→C;IF C≤A-3;
JMP -1⊦
```

XII — CALCULATES SUM OF PEAK DIFFERENCES AND STORES

```
44:
IF B=1;JMP 2⊦
```

```
45:
Ø→R25Ø;FXD 3;
PRT  .Ø18(R(A-2)/
(A-2Ø1))→R25Ø;
PRT"      INCHES";
SPC 8; JMP 2⊦
46:
Ø→R251;FXD 3;
PRT .Ø29(R(A-2)/
(A-2Ø1))→R251;
PRT"       INCHES";
SPC 8⊦
```

XIII — CALCULATES AND PRINTS FRINGE SPACING IN BOTH THE X & Y DIRECTION

```
47:
STP  ⊦
```

```
48:
PRT "DISTANCE BE
TWEEN";PRT "FRIN
GES IS"⊦
49:
PRT R251/Γ(1+R25
1R251/R25ØR25Ø)→
R252⊦
5Ø:
PRT"       INCHES";
SPC 1;PRT "AN
GLE WITH";PRT "R
ESPECT TO";PRT"
THE X-AXIS"⊦
51:
PRT ACS (R252/R2
51);PRT"
DEGREES";SPC 8⊦
```

XIV — FROM X & Y FRINGE SPACING THE ACTUAL FRINGE SPACING AND DIRECTION ARE PRINTED IN INCHES AND DEGREES, RESPECTIVELY

```
52:
END ⊦
R276
```

AD-A048 210 AIR FORCE AVIONICS LAB WRIGHT-PATTERSON AFB OHIO F/G 17/8
SPECKLEGRAM DATA REDUCTION USING OPTICAL AND DIGITAL TECHNIQUES--ETC(U)
NOV 77 C R LANE
UNCLASSIFIED AFAL-TR-77-203 NL

2 OF 2
AD
A048210

END
DATE
FILMED
1 -78
DDC

registers that contain fringe data or, in other words, registers with data more than $5x10^{-2}$ in amplitude. This information merely tells the programmer if noise contained in the systems will be above a certain threshold value set by the programmer ($5x10^{-2}$ in this case), and immediately following is Section VI which sets these noise values to absolute zero. The plots and printouts in Sections III, IV, AND V are mainly used to check the program for proper operation and are normally eliminated for general purposes by the jump 9 command in statement 9 of Section III. The first printout under normal operation, performed in Section VII, calculates the registers where the peaks of the fringes occur by a method of adjacent register comparison, and a resulting printout is executed in Section VIII. An example of this printout is shown in Figures 5a and 5b. These fringes will be discussed in more detail later in the report. Section Ix of the computer program simply asks the operator the direction in which the data was scanned in from Section I, and correspondingly enters a scale factor that has been manually precalculated to convert the scanning motor speeds into a recognizable format such as inches for this case. These two scale factors show up in Section XIII of the program as .018 for the y-direction and .029 for the x-direction. In Section X the data stored in Section VII are substracted and these differences are stored again for later use in Sections XI and XII. The eleventh program section is a safety feature installed to ensure that any peaks appearing as a result of noise in the system that were not eliminated previously are thrown out to prevent a false representation of fringe count. The fringe differences are now averaged over the entire data file in Section XII and the uni-directional (y) spacing is calculated with the motor speed scale factor employed to give an answer in inches. After storing this spacing in inches the entire procedure is initiated again the x-direction, by scanning the motor drive and this time using a different scale factor. As a result of Section XIII both x and y fringe spacing information is stored in R251 and R250, respectively. Stepping to the final section (XIV) registers R250 and R251 containing the x and y information, are inserted into a simple trigonometry function to determine the fringe spacing d and fringe angle θ which are the two answers being sought (see Figure 4D).

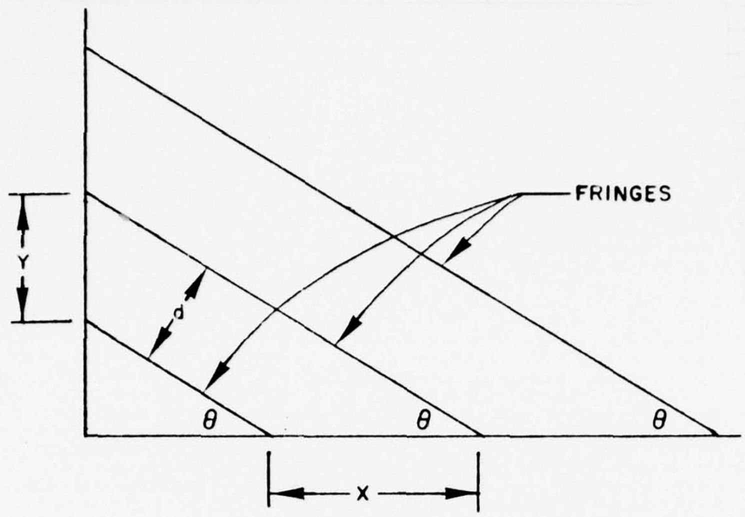


Figure 4D

Figures 5a and 5b illustrate the format in which the results were displayed. The answers of 5a were made from fringes spaced at .05 inch apart and 5b .10 inch apart, with angles for the two sets of fringes set approximately the same.

Finally 6 illustrates a method for checking the fringe angles, by simply plotting the fringe pattern in the x and y direction and graphically measuring the angle offset.

THE PEAKS ARE
AT REGISTERS

x

Ø
13
17
21
26
30
35
39

DISTANCE BETWEEN
FRINGES IN
X-DIRECTION IS

.126

INCHES

THE PEAKS ARE
AT REGISTERS

y

Ø
49
57
67
76

DISTANCE BETWEEN
FRINGES IN
Y-DIRECTION IS

.162

INCHES

DISTANCE BETWEEN
FRINGES IS

.Ø99

INCHES

ANGLE WITH
RESPECT TO
THE X-AXIS

37.ØØ1

DE[illegible]

Figure 5a

THE PEAKS ARE
AT REGISTERS

y

Ø
43
47
51
55
59
64
68
73

DISTANCE BETWEEN
FRINGES IN
Y-DIRECTION IS

.Ø77

INCHES

THE PEAKS ARE
AT REGISTERS

x

Ø
14
17
19
21
23
26
28
30
32
35
37
39

DISTANCE BETWEEN
FRINGES IN
X-DIRECTION IS

.Ø66

INCHES

DISTANCE BETWEEN
FRINGES IS

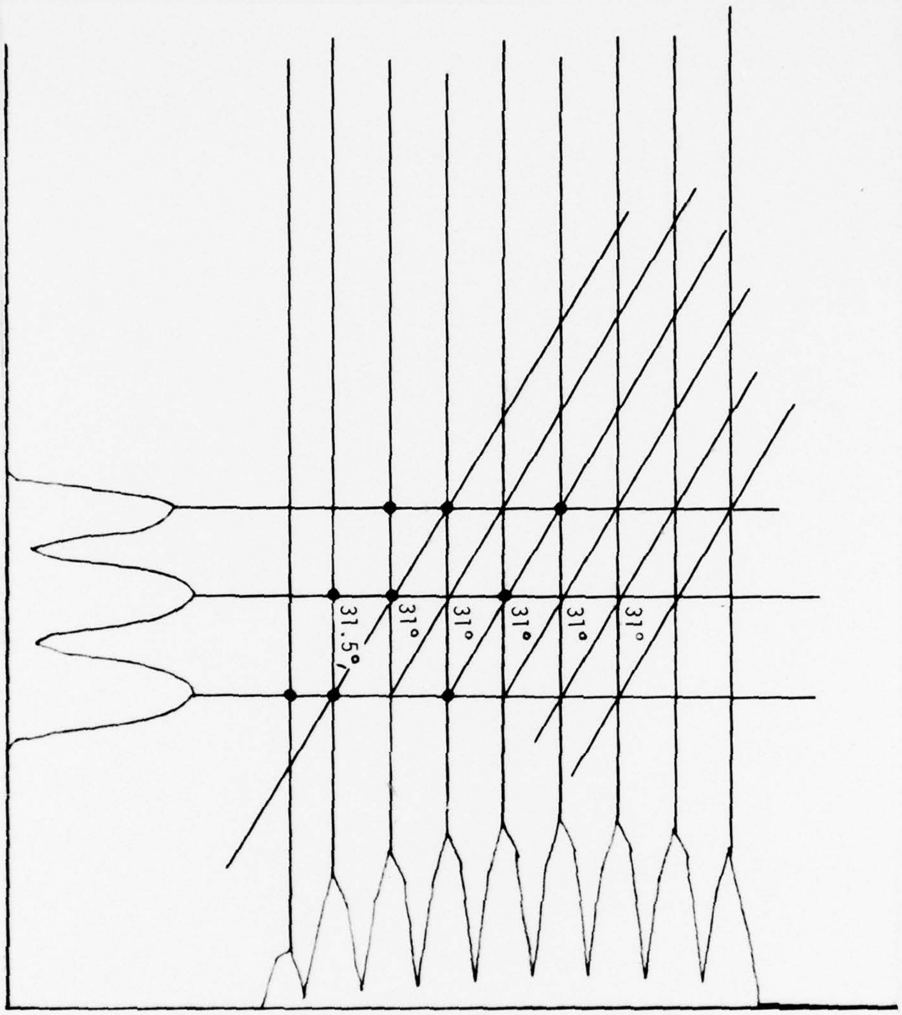
.Ø5Ø
INCHES

ANGLE WITH
RESPECT TO
THE X-AXIS
4Ø.51Ø

DEGREES

Figure 5b

```
Ø:
Ø→X;AXE Ø,Ø,Ø,Ø⊢
1:
RED 3,A,RX;IF (X
+1→X)≤1ØØ;JMP Ø⊢
2:
Ø→X;SCL Ø,1ØØ,Ø,
1⊢
3:
PLT 1.45X,RX;IF
(X+1→X)≤1ØØ;JMP
Ø⊢
4:
STP ⊢
5:
Ø→X⊢
6:
RED 3,A,RX;IF (X
+1→X)≤1ØØ;JMP Ø⊢
7:
Ø→X;SCL Ø,1,Ø,1Ø
Ø⊢
8:
PLT RX,.9X;IF (X
+1→X)≤1ØØ;JMP Ø⊢
9:
END ⊢
R395
```




```
THE PEAKS ARE
AT REGISTERS
Ø.ØØØØØØØØØE ØØ
1.4ØØØØØØØØE Ø1
2.6ØØØØØØØØE Ø1
3.6ØØØØØØØØE Ø1

DISTANCE BETWEEN
FRINGES IS
            .216
     INCHES

THE PEAKS ARE
AT REGISTERS
           Ø.ØØØ
           7.ØØØ
          11.ØØØ
          15.ØØØ
          19.ØØØ
          23.ØØØ
          27.ØØØ
          31.ØØØ
          35.ØØØ
          39.ØØØ

DISTANCE BETWEEN
FRINGES IS
            .116
     INCHES
DISTANCE BETWEEN
FRINGES IS
            .1Ø2
ANGLE WITH
RESPECT TO
THE X-AXIS
          28.237
```

Figure 6

CONCLUSION:

Our investigation as described here, indicates that several techniques may readily be applied to the type of fringe counting problem considered.

Several choices exist for reading out and for processing ("counting") fringe spacing. The choices of techniques (and optimum hardware implementation of same) depend heavily on the detailed technical and economic parameters and constraints of the application. Consideration of these details was beyond the scope of these initial feasibility investigations, since all equipment used in the demonstrations was presently available in-house.

The next logical step appears to be a design analysis to determine the optimum system configuration taking into account the detailed technical and economic factors. Following this, construction and testing of a prototype system would be appropriate.

AFAL/TEL would be pleased to undertake further work on this problem along the lines of the previous paragraph or as considered appropriate by mutual agreement of AFAL and FDL.

APPENDIX II

CONTROL PROGRAM PRINTOUT

```
SPECKLEGRAM ANALYSIS SYSTEM

MACRO VP05-01H 05-NOV-72 02:24 PAGE 1

 1                                                 .TITLE SPECKLEGRAM ANALYSIS SYSTEM
 2                                                 ;WITH DATA READ FROM RETICON
 3                                                 ;AND STEPPING STAGE
 4
 5                                                 .ENABLE    AMA
 6
 7
 8         000000                  R0=%0
 9         000001                  R1=%1
10         000002                  R2=%2
11         000003                  R3=%3
12         000004                  R4=%4
13         000005                  R5=%5
14         000006                  SP=%6
15         000007                  PC=%7
16         177560                  KBS=177560
17         177562                  KBB=177562
18         177564                  TPS=177564
19         177566                  TPB=177566
20
21
22         000000                                  .ASECT
23
24                                 ;MAIN  PROGRAM
25
26
27         000500                  .=500
28 000500  012706  000500          START: MOV #500,SP
29 000504  005037  005742                 CLR TRACK
30 000510  012700  006062                 MOV #ASKAV,R0              ;PRINT AVERAGE
31 000514  004737  004210                 JSR PC,TTYOUT
32 000520  012700  005762                 MOV #MEAN,R0
33 000524  004737  004320                 JSR PC,INPUT               ;ENTER NUMBER
34 000530  012700  005762                 MOV #MEAN,R0
35 000534  012702  005666                 MOV #KEEP,R2
36 000540  004737  001034                 JSR PC,ASCII               ;CONVERT TO OCTAL
37 000544  010337  005744                 MOV R3,TIMES               ;LOAD
38 000550  012737  000005  005736         MOV #5,XREAD               ;X
39 000556  012700  005776          JUMP:  MOV #XLIMIT,R0
40 000562  005020                  CLEAR: CLR (R0)+                  ;CLEAR STAGING LOCATIONS
41 000564  020027  006056                 CMP R0,#STEPX
42 000570  001374                         BNE CLEAR
43 000572  012700  006144                 MOV #XDIST,R0              ;PRINT X-DISTANCE
44 000576  004737  004210                 JSR PC,TTYOUT
45 000602  012700  005776                 MOV #XLIMIT,R0
46 000606  004737  004320                 JSR PC,INPUT               ;ENTER X-DISTANCE
47 000612  012700  005776                 MOV #XLIMIT,R0
```

SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
000616  012702  005666                  MOV #KEEP,R2
000622  004737  001034                  JSR PC,ASCII              ;CONVT TO OCTAL
000626  012700  005776                  MOV #XLIMIT,R0
000632  010310                          MOV R3,(R0)             ;LOAD
000634  012700  006234                  MOV #YDIST,R0
000640  004737  004210                  JSR PC,TTYOUT             ;PRINT "Y-DISTANCE"
000644  012700  006012                  MOV #YLIMIT,R0
000650  004737  004320                  JSR PC,INPUT             ;ENTER Y-DISTANCE
000654  012700  006012                  MOV #YLIMIT,R0
000660  012702  005666                  MOV #KEEP,R2
000664  004737  001034                  JSR PC,ASCII             ;CNVT TO OCTAL
000670  010337  006012                  MOV R3,YLIMIT
000674  012700  006324                  MOV #XINC,R0
000700  004737  004210                  JSR PC,TTYOUT             ;PRINT "X-INC"
000704  012700  006026                  MOV #INCX,R0
000710  004737  004320                  JSR PC,INPUT             ;ENTER X-INC
000714  012700  006374                  MOV #YINC,R0
000720  004737  004210                  JSR PC,TTYOUT;             PRINT "Y-INC"
000724  012700  006042                  MOV #INCY,R0
000730  004737  004320                  JSR PC,INPUT;             ENTER Y-INC
000734  012737  000004  164002          MOV #4,@#164002;             SET, +DIRECTION
000742  012700  006026                  MOV #INCX,R0
000746  012702  005666                  MOV #KEEP,R2
000752  004737  001034                  JSR PC,ASCII;             ;X-INC TO OCTAL
000756  013737  005644  006056          MOV OBUF,STEPX;             LOAD
000764  012700  006042                  MOV #INCY,R0
000770  012702  005666                  MOV #KEEP,R2
000774  004737  001034                  JSR PC,ASCII;             Y-STEP TO OCTAL
001000  012700  006576                  MOV #HEAD,R0;             PRINT HEADER
001004  004737  004210                  JSR PC,TTYOUT
001010  013737  005644  006060          MOV OBUF,STEPY
001016  004737  005132                  JSR PC,ASTAGE;             GTO STAGE ROUTINE
001022  012700  006460                  MOV #FIN,R0
001026  004737  004210                  JSR PC,TTYOUT;             PRINT "SCAN COMPLETE"
001032  000000                          HALT



001034  012001                  ASCII:  MOV (R0)+,R1;             CONVERT ASCII TO OCTAL
001036  162701  000060                  SUB #60,R1
001042  010122                          MOV R1,(R2)+
001044  021027  000015                  CMP (R0),#15
001050  001371                          BNE ASCII
001052  005003                          CLR R3
001054  014203                          MOV -(R2),R3;             LOAD LSD
001056  020227  005666                  CMP R2,#KEEP
001062  001465                          BEQ CMST
```

SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
001064  014205                   MOV -(R2),R5;          LOAD 2ND DIGIT
001066  005004                   CLR R4
001070  020527  000000           CMP R5,#0
001074  001405                   BEQ .+14
001076  062704  000012           ADD #12,R4 ;          10.
001102  162705  000001           SUB #1,R5
001106  000770                   BR .-16
001110  060403                   ADD R4,R3
001112  020227  005666           CMP R2,#KEEP
001116  001447                   BEQ CMST
001120  014205                   MOV -(R2),R5;          LOAD 3RD DIGIT
001122  005004                   CLR R4
001124  020527  000000           CMP R5,#0
001130  001405                   BEQ .+14
001132  062704  000144           ADD #144,R4;          100.
001136  162705  000001           SUB #1,R5
001142  000770                   BR .-16
001144  060403                   ADD R4,R3
001146  020227  005666           CMP R2,#KEEP
001152  001431                   BEQ CMST
001154  014205                   MOV -(R2),R5;          LOAD 5TH DIGIT
001156  005004                   CLR R4
001160  020527  000000           CMP R5,#0
001164  001405                   BEQ .+14
001166  062704  001750           ADD #1750,R4;          1000.
001172  162705  000001           SUB #1,R5
001176  000770                   BR .-16
001200  060403                   ADD R4,R3
001202  020227  005666           CMP R2,#KEEP
001206  001413                   BEQ CMST
001210  014205                   MOV -(R2),R5;          LOAD 5TH DIGIT
001212  005004                   CLR R4
001214  020527  000000           CMP R5,#0
001220  001405                   BEQ .+14
001222  062704  023420           ADD #23420,R4;          10000.
001226  162705  000001           SUB #1,R5
001232  000770                   BR .-16
001234  060403                   ADD R4,R3
001236  012701  005644   CMST:   MOV #OBUF,R1;          LOAD FINAL TO OBUF
001242  010311                   MOV R3,(R1)
001244  000207                   RTS PC


001246  000000           AMANIP:HALT
001250  012700  005604   MANIP:  MOV #RR0,R0
001254  005020           CLR1:   CLR (R0)+;           CLEAR WORKING REGISTERS
001256  020027  005704           CMP R0,#OBUF+2;        PLUS NONE,OBUF,FUNC
```

```
SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

001262  001374                      BNE CLR1:                 KEEP.FLG
001264  012700  007022              MOV #FBUFAV.R0
001270  005020            CLR2:     CLR (R0)+:                CLEAR FFT BUFFERS
001272  020027  010044              CMP R0.#FFTBUF+410
001276  001374                      BNE CLR2
001300  012704  007434              MOV #FFTBUF.R4
001304  004737  003216              JSR PC.AREAD:               GTO READ ROUTINE
001310  004737  001462              JSR PC.AFFT:              GTO FFT ROUTINE
001314  004737  004076              JSR PC.AAMP:              GTO AMPLITUDE ROUTINE
001320  004737  004516              JSR PC.AFREQ:               GTO FREQUENCY ROUTINE
001324  012700  006742              MOV #SPC.R0
001330  004737  004210              JSR PC.TTYOUT:               INSERT SPACES
001334  023727  005642  000001      CMP NONE.#1
001342  001005                      BNE HUMPS
001344  012700  006444              MOV #GOOF.R0
001350  004737  004210              JSR PC.TTYOUT:               PRINT "LOW
001354  000410                      BR NOLIST
001356  013700  005644    HUMPS:    MOV OBUF.R0
001362  004737  004754              JSR PC.OTD:               FREQUENCY TO DECIMAL
001366  012700  005704              MOV #DBUF+2.R0
001372  004737  004210              JSR PC.TTYOUT:               PRINT FREQUENCY
001376  005237  005746    NOLIST:   INC RATHER
001402  013737  005644  005756       MOV OBUF.ROBUF
001410  013737  005646  005760       MOV OBUF+2.ROBUF+2
001416  023727  005746  000002      CMP RATHER.#2
001424  001310                      BNE AMAN1P
001426  012700  006742              MOV #SPC.R0
001432  004737  004210              JSR PC.TTYOUT
001436  004737  003640              JSR PC.APRINT
001442  012700  006756    F4:       MOV #EOL.R0
001446  004737  004210              JSR PC.TTYOUT:               LF , CR
001452  000207            F3:       RTS PC
001454  000137  000500              JMP START
001460  000000                      HALT


001462  000000            AFFT:     HALT
001464  012700  007434    FFT:      MOV #FFTBUF.R0:               FFT SUBROUTINE
001470  012701  007436              MOV #FFTBUF+2.R1
001474  022120            NORMAL:   CMP (R1)+.(R0)+
001476  100001                      BPL STORE
001500  000775                      BR NORMAL
001502  162701  000002    STORE:    SUB #2.R1
001506  012103            ADO:      MOV (R1)+.R3
001510  021103            BDO:      CMP (R1).R3
001512  100375                      BPL ADO
001514  062701  000002              ADD #2.R1
```

```
SPECKLEGRAM ANALYSIS SYSTEM

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001520  020127  007644                    CMP R1,#FFTBUF+210
001524  001371                            BNE BDO
001526  020327  001000                    CMP R3,#1000
001532  001425                            BEQ CDO
001534  003016                            BGT DROP
001536  020327  000400                    CMP R3,#400
001542  003021                            BGT CDO
001544  006303                   SEE:     ASL R3
001546  012700  007434                    MOV #FFTBUF,R0
001552  006320                   UP:      ASL (R0)+
001554  020027  007644                    CMP R0,#FFTBUF+210
001560  001374                            BNE UP
001562  020327  000400                    CMP R3,#400
001566  003766                            BLE SEE
001570  000406                            BR CDO
001572  012700  007434           DROP:    MOV #FFTBUF,R0
001576  006220                   DOWN:    ASR (R0)+
001600  020027  007644                    CMP R0,#FFTBUF+210
001604  001374                            BNE DOWN
001606  012700  007434           CDO:     MOV #FFTBUF,R0
001612  012701  007444                    MOV #FFTBUF+10,R1
001616  012120                   SLIP:    MOV (R1)+,(R0)+
001620  020027  007654                    CMP R0,#FFTBUF+220
001624  001374                            BNE SLIP
001626  012737  000002  005626            MOV #2,RR9
001634  012737  000001  005604            MOV #1,RR0
001642  012737  000200  005610            MOV #200,RR2
001650  005700                            TST R0
001652  005001                            CLR R1
001654  012700  007434                    MOV #FFTBUF,R0
001660  006210                   SHIFT:   ASR (R0)
001662  005201                            INC R1
001664  020127  000003                    CMP R1,#3
001670  001373                            BNE SHIFT
001672  005001                            CLR R1
001674  062700  000002                    ADD #2,R0
001700  020027  010036                    CMP R0,#FFTBUF+402
001704  001365                            BNE SHIFT
001706  005700                   ALPHA:   TST R0
001710  012704  007434                    MOV #FFTBUF,R4
001714  006224                   KILL:    ASR (R4)+
001716  020427  010034                    CMP R4,#FFTBUF+400
001722  001374                            BNE KILL
001724  012737  000000  005606            MOV #0,RR1
001732  006237  005610                    ASR RR2
001736  005700                   BETA:    TST R0
001740  012704  010674                    MOV #COS,R4
```

SPECKLEGRAM ANALYSIS SYSTEM

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```
236 001744  063704  005624                  ADD RR8,R4
237 001750  011437  005612                  MOV (R4),RR3
238 001754  012704  011000                  MOV #SIN,R4
239 001760  063704  005624                  ADD RR8,R4
240 001764  011437  005614                  MOV (R4),RR4
241 001770  013737  005606  005616  L3:     MOV RR1,RR5
242 001776  005700                  GAMA:   TST R0
243 002000  013700  005616                  MOV RR5,R0
244 002004  062700  007434                  ADD #FFTBUF,R0  ;3000
245 002010  010037  005620                  MOV R0,RR6
246 002014  013701  005610                  MOV RR2,R1
247 002020  060001                          ADD R0,R1
248 002022  010137  005622                  MOV R1,RR7
249 002026  017700  003566          L5:     MOV @RR6,R0
250 002032  017701  003564                  MOV @RR7,R1
251 002036  060001                          ADD R0,R1
252 002040  010137  005632                  MOV R1,B
253 002044  013700  005620                  MOV RR6,R0
254 002050  062700  000200                  ADD #200,R0
255 002054  013701  005622                  MOV RR7,R1
256 002060  062701  000200                  ADD #200,R1
257 002064  011102                          MOV (R1),R2
258 002066  061002                          ADD (R0),R2
259 002070  010237  005634                  MOV R2,C
260 002074  013700  005620          L6:     MOV RR6,R0
261 002100  011004                          MOV (R0),R4
262 002102  013701  005622                  MOV RR7,R1
263 002106  161104                          SUB (R1),R4
264 002110  005005                          CLR R5
265 002112  013702  005612                  MOV RR3,R2
266 002116  005704                          TST R4
267 002120  100005                          BPL OTHER
268 002122  005702                          TST R2
269 002124  100020                          BPL MINUS
270 002126  005404                          NEG R4
271 002130  005402                          NEG R2
272 002132  000404                          BR  PLUS
273 002134  005702                  OTHER:  TST R2
274 002136  100002                          BPL PLUS
275 002140  005402                          NEG R2
276 002142  000411                          BR MINUS
277 002144  032704  000001          PLUS:   BIT #1,R4
278 002150  001401                          BEQ AZERO
279 002152  060205                          ADD R2,R5
280 002154  006302                  AZERO:  ASL R2
281 002156  006204                          ASR R4
282 002160  001371                          BNE PLUS
```

SPECKLEGRAM ANALYSIS SYSTEM

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```
002162  005004                           CLR R4
002164  000407                           BR LOAD
002166  005704                   MINUS:  TST R4
002170  100001                           BPL GOON
002172  005404                           NEG R4
002174  012737  000001  005664   GOON:   MOV #1.FLG
002202  000760                           BR PLUS
002204  005705                   LOAD:   TST R5
002206  100002                           BPL FUD1
002210  012705  077777                   MOV #77777,R5
002214  006205                   FUD1:   ASR R5
002216  005204                           INC R4
002220  020427  000011                   CMP R4.#11
002224  001373                           BNE FUD1
002226  023727  005664  000001           CMP FLG.#1
002234  001004                           BNE JUG
002236  005405                           NEG R5
002240  012737  000000  005664           MOV #0.FLG
002246  062700  000200           JUG:    ADD #200,R0
002252  062701  000200                   ADD #200.R1
002256  011102                           MOV (R1).R2
002260  161002                           SUB (R0).R2
002262  013704  005614                   MOV RR4.R4
002266  005003                           CLR R3
002270  005702                           TST R2
002272  100004                           BPL AG1
002274  005402                           NEG R2
002276  012737  000001  005664           MOV #1.FLG
002304  032702  000001           AG1:    BIT #1.R2
002310  001401                           BEQ BZERO
002312  060403                           ADD R4.R3
002314  006304                   BZERO:  ASL R4
002316  006202                           ASR R2
002320  001371                           BNE AG1
002322  005004                           CLR R4
002324  005703                   AG2:    TST R3
002326  100002                           BPL FUD2
002330  012703  077777                   MOV #77777,R3
002334  006203                   FUD2:   ASR R3
002336  005204                           INC R4
002340  020427  000011                   CMP R4.#11
002344  001373                           BNE FUD2
002346  023727  005664  000001           CMP FLG.#1
002354  001004                           BNE AG3
002356  012737  000000  005664           MOV #0.FLG
002364  005403                           NEG R3
002366  060305                   AG3:    ADD R3,R5
```

```
PECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

330 002370  010537  005630            MOV R5,A
331 002374  013700  005620    L7:     MOV RR6,R0
332 002400  01.004                    MOV (R0),R4
333 002402  013701  005622            MOV RR7,R1
334 002406  161104                    SUB (R1),R4
335 002410  005005                    CLR R5
336 002412  013702  005614            MOV RR4,R2
337 002416  005704                    TST R4
338 002420  100004                    BPL MULT4
339 002422  005404                    NEG R4
340 002424  012737  000001  005664    MOV #1,FLG
341 002432  032704  000001    MULT4:  BIT #1,R4
342 002436  001401                    BEQ DZERO
343 002440  060205                    ADD R2,R5
344 002442  006302            DZERO:  ASL R2
345 002444  006204                    ASR R4
346 002446  001371                    BNE MULT4
347 002450  005004                    CLR R4
348 002452  000400                    BR CHECK
349 002454  005705            CHECK:  TST R5
350 002456  100002                    BPL FUD3
351 002460  012705  077777            MOV #77777,R5
352 002464  006205            FUD3:   ASR R5
353 002466  005204                    INC R4
354 002470  020427  000011            CMP R4,#11
355 002474  001373                    BNE FUD3
356 002476  023727  005664  000001    CMP FLG,#1
357 002504  001004                    BNE EAT
358 002506  012737  000000  005664    MOV #0,FLG
359 002514  005405                    NEG R5
360 002516  062700  000200    EAT:    ADD #200,R0
361 002522  011002                    MOV (R0),R2
362 002524  062701  000200            ADD #200,R1
363 002530  161102                    SUB (R1),R2
364 002532  013703  005612            MOV RR3,R3
365 002536  005004                    CLR R4
366 002540  005703                    TST R3
367 002542  100005                    BPL DOT
368 002544  005702                    TST R2
369 002546  100020                    BPL LOW
370 002550  005402                    NEG R2
371 002552  005403                    NEG R3
372 002554  000404                    BR HIGH
373 002556  005702            DOT:    TST R2
374 002560  100002                    BPL HIGH
375 002562  005402                    NEG R2
376 002564  000411                    BR LOW
```

SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
002566  032702  000001          HIGH:   BIT #1,R2
002572  001401                          BEQ CZERO
002574  060304                          ADD R3,R4
002576  006303                  CZERO:  ASL R3
002600  006202                          ASR R2
002602  001371                          BNE HIGH
002604  005003                          CLR R3
002606  000407                          BR ALOAD
002610  005703                  LOW:    TST R3
002612  100001                          BPL GOONY
002614  005403                          NEG R3
002616  012737  000001  005664  GOONY:  MOV #1,FLG
002624  000760                          BR HIGH
002626  005704                  ALOAD:  TST R4
002630  100002                          BPL FUD4
002632  012704  077777                  MOV #77777,R4
002636  006204                  FUD4:   ASR R4
002640  005203                          INC R3
002642  020327  000011                  CMP R3,#11
002646  001373                          BNE FUD4
002650  023727  005664  000001          CMP FLG,#1
002656  001004                          BNE JUGGER
002660  005404                          NEG R4
002662  012737  000000  005664          MOV #0,FLG
002670  060405                  JUGGER:ADD R4,R5
002672  010511                          MOV R5,(R1)
002674  013777  005632  002716  L8.:    MOV B,@RR6
002702  013700  005620                  MOV RR6,R0
002706  062700  000200                  ADD #200,R0
002712  013710  005634                  MOV C,(R0)
002716  013777  005630  002676          MOV A,@RR7
002724  013705  005616          L9.:    MOV RR5,R5
002730  013702  005610                  MOV RR2,R2
002734  010200                          MOV R2,R0
002736  060200                          ADD R2,R0
002740  005700                          TST R0
002742  005700                          TST R0
002744  060005                          ADD R0,R5
002746  010537  005616                  MOV R5,RR5
002752  060205                  L10.:   ADD R2,R5
002754  020527  000177                  CMP R5,#177;                    ;JUGGLE FFT DATA
002760  003002                          BGT L11.
002762  000137  001776                  JMP GAMA
002766  062737  000002  005606  L11.:   ADD #2,RR1
002774  023737  005610  005606          CMP RR2,RR1
003002  001405                          BEQ L12.
003004  063737  005626  005624          ADD RR9,RR8
```

```
SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

003012  000137  001736                   JMP BETA
003016  062737  000001  005604  L12.:    ADD #1,RR0
003024  023727  005604  000006           CMP RR0,#6
003032  003007                           BGT D
003034  006337  005626                   ASL RR9
003040  012737  000000  005624           MOV #0,RR8
003046  000137  001706                   JMP ALPHA
003052  012737  000001  005610  D:       MOV #1,RR2;             FFT DONE
003060  012737  000001  005604  BEGIN:   MOV #1,RR0
003066  012737  000040  005606           MOV #40,RR1
003074  005004                           CLR R4
003076  013702  005610                   MOV RR2,R2
003102  013700  005604                   MOV RR0,R0
003106  013701  005606                   MOV RR1,R1
003112  030102                  TEST:    BIT R1,R2
003114  001401                           BEQ SLIDE
003116  060004                           ADD R0,R4
003120  006201                  SLIDE:   ASR R1
003122  006300                           ASL R0
003124  020127  000000                   CMP R1,#0
003130  001370                           BNE TEST
003132  020402                           CMP R4,R2
003134  002420                           BLT RECLR
003136  006302                           ASL R2
003140  006304                           ASL R4
003142  062702  007434                   ADD #FFTBUF,R2
003146  062704  007434                   ADD #FFTBUF,R4
003152  011203                           MOV (R2),R3
003154  011412                           MOV (R4),(R2)
003156  010314                           MOV R3,(R4)
003160  062702  000200                   ADD #200,R2
003164  062704  000200                   ADD #200,R4
003170  011203                           MOV (R2),R3
003172  011412                           MOV (R4),(R2)
003174  010314                           MOV R3,(R4)
003176  062737  000001  005610  RECLR:   ADD #1,RR2
003204  023727  005610  000100           CMP RR2,#100
003212  001322                           BNE BEGIN
003214  000207                           RTS PC
003216  000000                  AREAD:   HALT
003220  005002                  READ:    CLR R2;                 READ DATA FROM RETICON
003222  005005                           CLR R5
```

SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
003224  012737  000004  164000  CLOCK1:MOV #4.@#164000;              CLOCK PULSE
003232  012737  001005  176770         MOV #1005.@#176770;              CHANNEL 2
003240  013700  176770          DONE1: MOV @#176770.R0
003244  122700  000177                 CMPB #177.R0;              DONE READING ?
003250  100373                         BPL DONE1
003252  013701  176772                 MOV @#176772.R1;              LOAD A/D
003256  020127  000377                 CMP R1.#377;             DO I HAVE DATA ?
003262  100360                         BPL CLOCK1
003264  020527  000002                 CMP R5.#2;              DELAY
003270  001402                         BEQ WAIT
003272  005205                         INC R5
003274  000753                         BR CLOCK1
003276  005003                  WAIT:  CLR R3
003300  012737  000004  164000  CLOCK2:MOV #4.@#164000;              CLOCK PULSE
003306  005202                         INC R2
003310  020227  000202                 CMP R2.#202;               SKIP DEAD TIME
003314  001405                         BEQ CLOCK3
003316  005203                  SLOW:  INC R3
003320  020327  000005                 CMP R3.#5;              DELAY
003324  001374                         BNE SLOW
003326  000763                         BR WAIT
003330  005237  005640          CLOCK3:INC SECOND;         XREAD OR YREAD
003334  023737  005640  005744         CMP SECOND.TIMES
003342  003035                         BGT CLOCK5
003344  012737  000004  164000  CLOCK4:MOV #4.@#164000;              CLOCK PULSE-X
003352  013737  005736  176770         MOV XREAD.@#176770
003360  013705  176770          DONE2: MOV @#176770.R5
003364  122705  000177                 CMPB #177.R5;               ;DONE ?
003370  100373                         BPL DONE2
003372  013724  176772          AVER:  MOV @#176772.(R4)+;            LOAD A/D
003376  005700                         TST R0
003400  005700                         TST R0
003402  005700                         TST R0
003404  005700                         TST R0
003406  023727  005740  000001          CMP WHICH.#1;             ;AVERAGE
003414  001004                          BNE LOOP1
003416  020427  007232                  CMP R4.#FBUFAV+210;              AVERAGE -X
003422  001350                          BNE CLOCK4
003424  000434                          BR DNREAD
003426  020427  007644          LOOP1:  CMP R4.#FFTBUF+210
003432  001344                         BNE CLOCK4
003434  000430                         BR DNREAD
003436  012737  000004  164000  CLOCK5:MOV #4.@#164000;             CLOCK PULSE-Y
003444  012737  000405  176770         MOV #405.@#176770
003452  013705  176770          DONE3: MOV @#176770.R5
003456  122705  000177                 CMPB #177.R5
003462  100373                         BPL DONE3
```

SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
003464  013724  176772                   MOV @#176772,(R4)+
003470  023727  005740  000001            CMP WHICH,#1
003476  001004                            BNE LOOP2
003500  020427  007232                    CMP R4,#FBUFAV+210
003504  001354                            BNE CLOCK5
003506  000403                            BR DNREAD
003510  020427  007644          LOOP2:    CMP R4,#FFTBUF+210
003514  001350                           BNE CLOCK5
003516  005237  005742          DNREAD:INC TRACK
003522  023737  005742  005744            CMP TRACK,TIMFS
003530  001424                            BEQ FOWARD
003532  023727  005742  000001            CMP TRACK,#1
003540  001412                            BEQ DUPRED
003542  012702  007434                    MOV #FFTBUF,R2
003546  012705  007022                    MOV #FBUFAV,R5
003552  006212                  ALOOP:    ASR (R2)
003554  006215                            ASR (R5)
003556  062522                            ADD (R5)+,(R2)+
003560  020227  007644                    CMP R2,#FFTBUF+210
003564  001372                            BNE ALOOP
003566  012737  000001  005740  DUPRED:   MOV #1,WHICH
003574  012704  007022                    MOV #FBUFAV,R4
003600  000606                            BR AREAD
003602  005037  005742          FOWARD:   CLR TRACK
003606  005037  005740                    CLR WHICH
003612  012700  007444                    MOV #FFTBUF+10,R0;         LOAD 1ST HALF DATA TO 2ND HALF
003616  012701  007644                    MOV #FFTBUF+210,R1
003622  011120                  CIRCLE:MOV (R1),(R0)+
003624  162701  000002                   SUB #2,R1
003630  020027  007544                   CMP R0,#FFTBUF+110
003634  001372                           BNE CIRCLE
003636  000207                           RTS PC

003640  000000                  APRINT:HALT
003642  005037  005752          PRINT:    CLR YDISTO
003646  005037  005750                    CLR XDISTO
003652  012705  000100                    MOV #100,R5
003656  163705  005756                    SUB ROBUF,R5
003662  005237  005750                    INC XDISTO
003666  020527  000000                    CMP R5,#0
003672  003371                           BGT .-14
003674  012705  000100                    MOV #100,R5
003700  163705  005644                    SUB OBUF,R5
```

SPECKLEGRAM ANALYSIS SYSTEM

MACRO VR05-01H 05-NOV-72 02:24 PAGE 1+

```
003704  005237  005752            INC YDISTO
003710  020527  000000            CMP R5,#0
003714  003371                    BGT .-14
003716  004737  003760            JSR PC,AANGLE;          GTO ANGLE
003722  012700  005706            MOV #DBUF+4,R0;         LOAD FOR ANGLE LIST
003726  004737  004210            JSR PC,TTYOUT
003732  012700  006742            MOV #SPC,R0
003736  004737  004210            JSR PC,TTYOUT;          INSERT SPACES
003742  004737  004424            JSR PC,ADISP             ; GTO TO DISPLACEMENT
003746  012700  005706            MOV #DBUF+4,R0,
003752  004737  004210            JSR PC,TTYOUT
003756  000207                    RTS PC

003760  000000            AANGLE:HALT
003762  005000            ANGLE: CLR R0
003764  013703  005752            MOV YDISTO,R3;          Y-SPACING
003770  013704  005750            MOV XDISTO,R4;          X-SPACING
003774  006303            MULT1: ASL R3;                  MULTIPLYING BY 100-8
003776  005200                    INC R0
004000  020027  000006            CMP R0,#6
004004  001373                    BNE MULT1
004006  005000                    CLR R0
004010  160403            DOCIR: SUB R4,R3  ;             DIVIDE Y BY X
004012  062700  000001            ADD #1,R0
004016  020327  000000            CMP R3,#0
004022  001372                    BNE DOCIR
004024  012705  010134            MOV #TANBUF,R5;         LOAD TANGENT ADDRESS
004030  020025            LOOKUP:CMP R0,(R5)+;             LOOK FOR ANGLE
004032  100376                    BPL LOOKUP
004034  162705  000004            SUB #4,R5
004040  162705  010134            SUB #TANBUF,R5;         ABSOLUTE ANGLE-DEGREES
004044  010537  005754            MOV R5,RATIO;           LOAD ANGLE
004050  006205            DIVANG:ASR R5;                  DIVIDE BY TWO
004052  012704  005702            MOV #DBUF,R4
004056  005024            DBUFCL:CLR (R4)+
004060  020427  005720            CMP R4,#DBUF+16
004064  001374                    BNE DBUFCL
004066  010500                    MOV R5,R0;              LOAD FOR OTD
004070  004737  004754            JSR PC,OTD
004074  000207                    RTS PC
```

```
SPECKLEGRAM ANALYSIS SYSTEM

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    004076  000000                  AAMP:   HALT
    004100  012700  007434          AMP:    MOV #FFTBUF,R0;              REAL BUFFERS
    004104  012701  007634                  MOV #FFTBUF+200,R1;             IMAGINARY BUFFER
    004110  005710                  SQR1:   TST (R0);              IS REAL POSITIVE ?
    004112  100001                          BPL SQR2
    004114  005410                          NEG (R0);              IF NOT NEGATE
    004116  005711                  SQR2:   TST (R1);              IS IMAGINARY POSITIVE
    004120  100001                          BPL SQR3
    004122  005411                          NEG (R1);              IF NOT NEGATE
    004124  005004                  SQR3:   CLR R4
    004126  011003                          MOV (R0),R3
    004130  032703  000001          NOTE1:  BIT #1,R3
    004134  001401                          BEQ SQR4
    004136  061004                          ADD (R0),R4;            SQUARE REAL PART
    004140  006310                  SQR4:   ASL (R0)
    004142  006203                          ASR R3
    004144  001371                          BNE NOTE1
    004146  005005                          CLR R5
    004150  011103                          MOV (R1),R3
    004152  032703  000001          NOTE2:  BIT #1,R3
    004156  001401                          BEQ SQR5
    004160  061105                          ADD (R1),R5;              SQUARE IMAGINARY PART
    004162  006311                  SQR5:   ASL (R1)
    004164  006203                          ASR R3
    004166  001371                          BNE NOTE2
    004170  060405                          ADD R4,R5;              ADD REAL AND IMAGINARY
    004172  010520                          MOV R5,(R0)+
    004174  062701  000002                  ADD #2,R1
    004200  020027  007634                  CMP R0,#FFTBUF+200
    004204  001341                          BNE SQR1
    004206  000207                          RTS PC

    004210  105737  177564          TTYOUT:TSTB TPS;               READY TO PRINT
    004214  100375                          BPL TTYOUT
    004216  012037  177566                  MOV (R0)+,TPB;             ;PRINT
    004222  021027  000000                  CMP (R0),#0
    004226  001370                          BNE TTYOUT
    004230  000207                          RTS PC
```

SPECKLEGRAM ANALYSIS SYSTEM

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```


004232  021027  000123          OPER:  CMP (R0),#123;          S ?
004236  001003                         BNE N1
004240  012705  000000                 MOV #0,R5
004244  000207                         RTS PC
004246  021027  000130          N1:    CMP (R0),#130;           X ?
004252  001003                         BNE N2
004254  012705  000001                 MOV #1,R5
004260  000207                         RTS PC
004262  021027  000131          N2:    CMP (R0),#131;           Y ?
004266  001003                         BNE N3
004270  012705  000002                 MOV #2,R5
004274  000207                         RTS PC
004276  021027  000104          N3:    CMP (R0),#104;           D ?
004302  001003                         BNE N4
004304  012705  000003                 MOV #3,R5
004310  000207                         RTS PC
004312  012705  000004          N4:    MOV #4,R5
004316  000207                         RTS PC




004320  105737  177560          INPUT: TSTB KBS;             KEYBOARD READY ?
004324  100375                         BPL INPUT
004326  013704  177562                 MOV KBB,R4;             KEYBOARD TO REGISTER
004332  042704  177600                 BIC #177600,R4;             CLEAR PARITY BIT
004336  010420                         MOV R4,(R0)+
004340  105737  177564          ECHO:  TSTB TPS;             READY TO PRINT
004344  100375                         BPL ECHO
004346  020427  000177                 CMP R4,#177;              CHECK FOR RUBOUT
004352  001010                         BNE E1
004354  012737  000134  177566         MOV #134,TPB;              MOV / TO PRINTER
004362  012740  000000                 MOV #0,-(R0);              CANCEL OLD
004366  012740  000000                 MOV #0,-(R0)
004372  000752                         BR INPUT
004374  010437  177566          E1:    MOV R4,TPB;             PRINT NEW
004400  020427  000015                 CMP R4,#15
004404  001345                         BNE INPUT
004406  105737  177564          LNFD:  TSTB TPS
004412  100375                         BPL LNFD
004414  012737  000012  177566         MOV #12,TPB;              LINE FEED
004422  000207                         RTS PC

004424  012701  010422          ADISP:  MOV #SINBUF,R1;        .  LOAD SIN START ADDRESS
004430  063701  005754                 ADD RATIO,R1;              ADD ANGLE ADDRESS
```

SPECKLEGRAM ANALYSIS SYSTEM

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```
004434  011102                           MOV (R1),R2;            LOAD SIN
004436  013703  005750                   MOV XDISTO,R3;          LOAD XSPACING
004442  005000                           CLR R0
004444  060200                   MULT6:  ADD R2,R0;              MULT XSIN ANGLE
004446  162703  000001                   SUB #1,R3
004452  020327  000000                   CMP R3,#0
004456  001372                           BNE MULT6
004460  005003                           CLR R3
004462  006200                   LESSOR:ASR R0 :                 DIVIDE BY 100-8
004464  005203                           INC R3
004466  020327  000006                   CMP R3,#6
004472  001373                           BNE LESSOR
004474  012704  005702                   MOV #DBUF,R4;           LOAD TO CLEAR
004500  005024                   DWIPE:  CLR (R4)+
004502  020427  005720                   CMP R4,#DBUF+16
004506  001374                           BNE DWIPE
004510  004737  004754                   JSR PC,OTD
004514  000207                           RTS PC



004516  000000                   AFREQ:  HALT
004520  005037  005734           FREQ:   CLR HIDC
004524  023727  007632  000156           CMP FFTBUF+176,#156;       CHECK FOR HI DC
004532  002003                           BGE HOP
004534  012737  000001  005734           MOV #1,HIDC
004542  012700  007574           HOP:    MOV #FFTPUF+140,R0;       INITIALIZE FOR HIGHEST FREQUENCY
004546  005003                           CLR R3
004550  022003                   SRCH:   CMP (R0)+,R3;           CHECK IF LAST HIGHER
004552  003004                           BGT HOLD
004554  020027  007630                   CMP R0,#FFTBUF+174;          DONE ?
004560  003773                           BLE SRCH
004562  000426                           BR QUIT
004564  023727  005734  000001   HOLD:   CMP HIDC,#1;           CHECK HIDC SET
004572  001006                           BNE SKIP
004574  162700  000002                   SUB #2,R0
004600  022027  000003                   CMP (R0)+,#3
004604  003412                           BLE QUIT-6
004606  000405                           BR VALID
004610  162700  000002           SKIP:   SUB #2,R0;         SKIP FREQ SRCH FOR HIDC
004614  022027  000010                   CMP (R0)+,#10
004620  003404                           BLE QUIT-6
004622  162700  000002           VALID:  SUB #2,R0
004626  010002                           MOV R0,R2
004630  012003                           MOV (R0)+,R3
004632  020027  007630                   CMP R0,#FFTBUF+174
004636  003744                           BLE SRCH
```

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```
004640  005037  005642          QUIT:   CLR NONE
004644  020327  000000                  CMP R3,#0
004650  001003                          BNE FOW
004652  005237  005642                  INC NONE
004656  000435                          BR OVER
004660  062702  000002          FOW :   ADD #2,R2;              INTERPOLATE
004664  011200                          MOV (R2),R0
004666  162702  000004                  SUB #4,R2
004672  021200                          CMP (R2),R0
004674  003003                          BGT MORE
004676  012705  000000                  MOV #0,R5
004702  000402                          BR LIST
004704  012705  000001          MORE:   MOV #1,R5
004710  062702  000002          LIST:   ADD #2,R2
004714  012701  007634                  MOV #FFTBUF+200,R1
004720  160201                          SUB R2,R1
004722  006201                          ASR R1
004724  012700  005644                  MOV #OBUF,R0
004730  010120                          MOV R1,(R0)+
004732  020527  000001                  CMP R5,#1
004736  001003                          BNE LESS
004740  012710  000053                  MOV #53,(R0)
004744  000402                          BR OVER
004746  012710  000055          LESS:   MOV #55,(R0)
004752  000207                  OVER:   RTS PC








004754  012701  005702          OTD:    MOV #DBUF,R1
004760  005002                          CLR R2
004762  020027  023420                  CMP R0,#23420;             10000.
004766  002405                          BLT .+14
004770  162700  023420                  SUB #23420,R0
004774  062702  000001                  ADD #1,R2
005000  000770                          BR .-16
005002  062702  000060                  ADD #60,R2;             ASCII
005006  010221                          MOV R2,(R1)+
005010  005002                          CLR R2
005012  020027  001750                  CMP R0,#1750;              1000.
005016  002405                          BLT .+14
005020  162700  001750                  SUB #1750,R0
005024  062702  000001                  ADD #1,R2
```

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SPECKLEGRAM ANALYSIS SYSTEM

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    005030  000770                            BR .-16
    005032  062702  000060                    ADD #60,R2;          ASCII
    005036  010221                            MOV R2,(R1)+
    005040  005002                            CLR R2
    005042  020027  000144                    CMP R0,#144
    005046  002405                            BLT .+14
    005050  162700  000144                    SUB #144,R0;          100.
    005054  062702  000001                    ADD #1,R2
    005060  000770                            BR .-16
    005062  062702  000060                    ADD #60,R2;           ASCII
    005066  010221                            MOV R2,(R1)+
    005070  005002                            CLR R2
    005072  020027  000012                    CMP R0,#12
    005076  002405                            BLT .+14
    005100  162700  000012                    SUB #12,R0;           10.
    005104  062702  000001                    ADD #1,R2
    005110  000770                            BR .-16
    005112  062702  000060                    ADD #60,R2;          ASCII
    005116  010221                            MOV R2,(R1)+
    005120  005002                            CLR R2
    005122  062700  000060                    ADD #60,R0;           LSD
    005126  010021                            MOV R0,(R1)+;           LOAD TO DBUF
    005130  000207                            RTS PC




    005132  000000                    ASTAGE:HALT
    005134  005037  005730            STAGE:  CLR COLM
    005140  005037  005724                    CLR LINE
    005144  005037  005722                    CLR UNIT
    005150  005037  005726                    CLR DELAY
    005154  012737  000001  164000    XSTEP:  MOV #1,@#164000;             X-STAGE PULSE
    005162  062737  000001  005722            ADD #1,UNIT;         KEEP TRACK
    005170  062737  000001  005724            ADD #1,LINE
    005176  005237  005726            XLOOP:  INC DELAY;          DELAY
    005202  023727  005726  000100            CMP DELAY,#100
    005210  001372                            BNE XLOOP
    005212  005037  005726                    CLR DELAY
    005216  023737  005722  006056            CMP UNIT,STEPX;           DONE INC SCAN ?
    005224  001353                            BNE XSTEP
    005226  005037  005722                    CLR UNIT
    005232  004737  005502                    JSR PC,POSITN:          GTO POSITN
    005236  004737  001246                    JSR PC,OMANIP;         GTO MANIP
    005242  005037  005746                    CLR RATHER
    005246  013737  005776  005722            MOV XLIMIT,UNIT
    005254  023737  005724  005722            CMP LINE,UNIT;            DONE LINE SCAN ?
```

'ECKLEGRAM ANALYSIS SYSTEM

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```
005262  100730                           BMI XSTEP-10
005264  000443                           BR ZEROX
005266  012737  000002  164000  YSTEP:   MOV #2.@#164000;         Y-STAGE PULSE
005274  062737  000001  005726           ADD #1.DELAY;           KEEP TRACK
005302  062737  000001  005730           ADD #1.COLM
005310  005237  005722          YLOOP:   INC UNIT
005314  023727  005722  000100           CMP UNIT.#100;           DELAY
005322  001372                           BNE YLOOP
005324  005037  005722                   CLR UNIT
005330  023737  005726  006060           CMP DELAY.STEPY;        DONE Y-INC SCAN
005336  001353                           BNE YSTEP
005340  004737  005502                   JSR PC.POSITN;          GTO POSITN
005344  004737  001246                   JSR PC.AMANIP;           GTO MANIP
005350  005037  005746                   CLR RATHER
005354  013737  006012  005722           MOV YLINIT.UNIT;          DONE Y-SCAN
005362  023737  005730  005722           CMP COLM.UNIT
005370  003665                           BLE XSTEP-10
005372  000207                           RTS PC
005374  012737  000001  164002  ZEROX:   MOV #1.@#164002;         CHANGE X SIGN
005402  012737  000001  164000  XZERO:   MOV #1.@#164000;           XPULSE
005410  162737  000001  005724           SUB #1.LINE
005416  005237  005722          DOLOOP:  INC UNIT
005422  023727  005722  000100           CMP UNIT.#100;           DELAY
005430  001372                           BNE DOLOOP
005432  005037  005722                   CLR UNIT
005436  023727  005724  000000           CMP LINE.#0;            DONE ZEROING X ?
005444  001356                           BNE XZERO
005446  005237  005722          ROUND:   INC UNIT
005452  023727  005722  040000           CMP UNIT.#40000;            DELAY
005460  001372                           BNE ROUND
005462  005037  005722                   CLR UNIT
005466  005037  005726                   CLR DELAY
005472  012737  000004  164002           MOV #4.@#164002;           CHANGE XSIGN TO +
005500  000672                           BR YSTEP


005502  012700  005702          POSITN:  MOV #DBUF.R0;          LOAD POSITION BUFFER
005506  005020                  DCLEAR:  CLR (R0)+
005510  020027  005714                   CMP R0.#DBUF+12;           CLEAR POSITN BUFFER
005514  001374                           BNE DCLEAR
005516  013700  005724                   MOV LINE.R0;         LOAD X-POSITION
005522  004737  004754                   JSR PC.OTD;         CNVT TO DECIMAL
005526  012700  005702                   MOV #DBUF.R0
005532  004737  004210                   JSR PC.TTYOUT;          PRINT X-POSITION
005536  013700  005730                   MOV COLM.R0;         LOAD Y-POSITION
005542  004737  004754                   JSR PC.OTD;          CONVERT TO DECIMAL
005546  012700  006742                   MOV #SPC.R0
```

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```
005552  004737  004210                   JSR PC,TTYOUT;            INSERT SPACES
005556  012700  005702                   MOV #DBUF,R0
005562  004737  004210                   JSR PC,TTYOUT;             PRINT Y-POSITION
005566  012700  006056                   MOV #STEPX,R0;            RELOAD X-Y STEP
005572  012701  006060                   MOV #STEPY,R1
005576  005037  005722                   CLR UNIT
005602  000207                           RTS PC
005604  000000                   RR0:    .WORD 0;              FFT WORKING BUFFERS
005606  000000                   RR1:    .WORD 0
005610  000000                   RR2:    .WORD 0
005612  000000                   RR3:    .WORD 0
005614  000000                   RR4:    .WORD 0
005616  000000                   RR5:    .WORD 0
005620  000000                   RR6:    .WORD 0
005622  000000                   RR7:    .WORD 0
005624  000000                   RR8:    .WORD 0
005626  000000                   RR9:    .WORD 0
005630  000000                   A:      .WORD 0
005632  000000                   B:      .WORD 0
005634  000000                   C:      .WORD 0
005636  000000                   X:      .WORD 0
005640  000000                   SECOND:.WORD 0;               0 FOR X,1 FOR Y
005642  000000                   NONE:   .WORD 0
005644  000000  000000           OBUF:   .WORD 0,0
005650  000000  000000  000000   FUNC:   .WORD 0,0,0,0,0,0
005656  000000  000000  000000
005664  000000                   FLG:    .WORD 0
005666  000000  000000  000000   KEEP:   .WORD 0,0,0,0,0,0
005674  000000  000000  000000
005702  000000  000000  000000   DBUF:   .WORD 0,0,0,0,0,0,0,0
005710  000000  000000  000000
005716  000000  000000
005722  000000                   UNIT:   .WORD 0
005724  000000                   LINE:   .WORD 0
005726  000000                   DELAY:  .WORD 0
005730  000000                   COLM:   .WORD 0
005732  000000                   SOEZ:   .WORD 0
005734  000000                   HIDC:   .WORD 0
005736  000000                   XREAD:  .WORD 0
005740  000000                   WHICH:   .WORD 0
005742  000000                   TRACK:  .WORD 0
005744  000000                   TIMES:  .WORD 0
005746  000000                   RATHER:.WORD 0
005750  000000                   XDISTO:.WORD 0
005752  000000                   YDISTO:.WORD 0
```

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SPECKLEGRAM ANALYSIS SYSTEM

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937 005754 000000                      RATIO: .WORD 0
938 005756 000000  000000              RUBUF: .WORD 0,0
939 005762 000000  000000  000000      MEAN:  .WORD 0.0.0.0.0.0
    005770 000000  000000  000000
940 005776 000000  000000  000000      XLIMIT:.WORD 0.0.0.0.0.0
    006004 000000  000000  000000
941 006012 000000  000000  000000      YLIMIT:.WORD 0.0.0.0.0.0
    006020 000000  000000  000000
942 006026 000000  000000  000000      INCX:  .WORD 0.0.0.0.0.0
    006034 000000  000000  000000
943 006042 000000  000000  000000      INCY:  .WORD 0.0.0.0.0.0
    006050 000000  000000  000000
944 006056 000000                     .STEPX: .WORD 0
945 006060 000000                      STEPY: .WORD 0
946 006062 000015  000012  000012      ASKAV: .WORD 15.12.12
947 006070 000116  000117  000056             .WORD 116.117.56.43.40.104;       NO.* DATA AVERAGES
    006076 000043  000040  000104
948 006104 000101  000124  000101             .WORD 101.124.101.40.101.126
    006112 000040  000101  000126
949 006120 000105  000122  000101             .WORD 105.122.101.107.105
    006126 000107  000105
950 006132 000123  000040  000054             .WORD 123.40.54.40.0
    006140 000040  000000
951 006144 000015  000012  000012      XDIST: .WORD 15.12.12
952 006152 000130  000055  000124             .WORD 130.55.124.117.124;         X-TOT SCAN DISTANCE
    006160 000117  000124
953 006164 000040  000123  000103             .WORD 40.123.103.101.116
    006172 000101  000116
954 006176 000040  000104  000111             .WORD 40.104.111.123.124
    006204 000123  000124
955 006210 000101  000116  000103             .WORD 101.116.103.105.40
    006216 000105  000040
956 006222 000077  000040  000054             .WORD 77.40.54.40.0
    006230 000040  000000
957 006234 000015  000012  000012      YDIST: .WORD 15.12.12
958 006242 000131  000055  000124             .WORD 131.55.124.117.124;         Y-TOT SCAN DISTANCE
    006250 000117  000124
959 006254 000040  000123  000103             .WORD 40.123.103.101.116
    006262 000101  000116
960 006266 000040  000104  000111             .WORD 40.104.111.123.124
    006274 000123  000124
961 006300 000101  000116  000103             .WORD 101.116.103.105.40
    006306 000105  000040
962 006312 000077  000040  000054             .WORD 77.40.54.40.0
    006320 000040  000000
963 006324 000015  000012  000012      XINC:  .WORD 15.12.12
964 006332 000130  000055  000111             .WORD 130.55.111.116.103;         X-INCREMENT
```

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SPECKLEGRAM ANALYSIS SYSTEM

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    006340 000116 000103
965 006344 000122 000105 000115          .WORD 122,105,115,105,116
    006352 000105 000116
966 006356 000124 000040 000077          .WORD 124,40,77,40,54
    006364 000040 000054
967 006370 000040 000000                 .WORD 40,0
968 006374 000015 000012 000012  YINC:   .WORD 15,12,12
969 006402 000131 000055 000111          .WORD 131,55,111,116,103;          Y-INCREMENT
    006410 000116 000103
970 006414 000122 000105 000115          .WORD 122,105,115,105,116
    006422 000105 000116
971 006426 000124 000040 000077          .WORD 124,40,77,40,54
    006434 000040 000054
972 006440 000040 000000                 .WORD 40,0
973 006444 000114 000117 000127  GOOF:   .WORD 114,117,127,0,0,0;           LOW
    006452 000000 000000 000000
974 006460 000015 000012 000012  FIN:    .WORD 15,12,12,12,12
    006466 000012 000012
975 006472 000130 000055 000131          .WORD 130,55,131,40,123;           X-Y SCAN COMPLETED
    006500 000040 000123
976 006504 000103 000101 000116          .WORD 103,101,116,40,103
    006512 000040 000103
977 006516 000117 000115 000120          .WORD 117,115,120,114,105
    006524 000114 000105
978 006530 000124 000105 000104          .WORD 124,105,104,15,12
    006536 000015 000012
979 006542 000012 000012 000012          .WORD 12,12,12,12,12
    006550 000012 000012
980 006554 000012 000012 000012          .WORD 12,12,12,12,12,12
    006562 000012 000012 000012
981 006570 000012 000012 000000          .WORD 12,12,0
982 006576 000015 000012 000012  HEAD:   .WORD 15,12,12,40,40
    006604 000040 000040
983 006610 000130 000040 000040          .WORD 130,40,40,40,40
    006616 000040 000040
984 006622 000040 000040 000040          .WORD 40,40,40,40,40,131
    006630 000040 000040 000131
985 006636 000040 000040 000040          .WORD 40,40,40,40,40,40,40
    006644 000040 000040 000040
    006652 000040
986 006654 000106 000122 000105          .WORD 106,122,105,121
    006662 000121
987 006664 000040 000040 000040          .WORD 40,40,40,40,40
    006672 000040 000040
988 006676 000130 000055 000123          .WORD 130,55,123,120,103
    006704 000120 000103
989 006710 000040 000040 000040          .WORD 40,40,40,40
```

:KLEGRAM ANALYSIS SYSTEM

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```
     006716  000040
990  006720  000131  000055  000123          .WORD 131,55,123,120,103
     006726  000120  000103
991  006732  000015  000012  000012          .WORD 15,12,12,0
     006740  000000
992  006742  000040  000040  000040  SPC:    .WORD 40,40,40,40,40,0;         5 SPACES
     006750  000040  000040  000000
993  006756  000015  000012  000000  EOL:    .WORD 15,12,0,0,0,0;            CR,LF
     006764  000000  000000  000000
994  006772  000106  000122  000105  CYCLES:.WORD 106,122,105,121,125,105;  FREQUENCY
     007000  000121  000125  000105
995  007006  000116  000103  000131          .WORD 116,103,131,75,40,0
     007014  000075  000040  000000
996  007022  000000                  FBUFAV:.WORD 0:                        FFT BUFFERS
997          007434                           .=.+410
998  007434  000000                  FFTBUF:.WURD 0
999          010046                          .=.+410
1000 010046  000015  000012  000012  DATA:   .WORD 15,12,12
1001 010054  000114  000111  000123          .WORD 114,111,123,124,105;      LISTED ?
     010062  000124  000105
1002 010066  000104  000040  000077          .WORD 104,40,77,40,0
     010074  000040  000000
1003 010100  000015  000012  000012  QUES:   .WORD 15,12,12
1004 010106  000117  000125  000124          .WORD 117,125,124,120,125,124;  OUTPUT
     010114  000120  000125  000124
1005 010122  000040  000077  000040          .WORD 40,77,40,0,0
     010130  000000  000000
1006
1007
1008
1009 010134  000000  000001  000002  TANBUF:.WORD 0,1,2,3,4,5
     010142  000003  000004  000005
1010 010150  000006  000007  000010          .WORD 6,7,10,12,13,14
     010156  000012  000013  000014
1011 010164  000015  000016  000017          .WORD 15,16,17,21,22
     010172  000021  000022
1012 010176  000023  000024  000026          .WORD 23,24,26,27,30
     010204  000027  000030
1013 010210  000031  000033  000034          .WORD 31,33,34,35,37
     010216  000035  000037
1014 010222  000040  000042  000043          .WORD 40,42,43,44,46
     010230  000044  000046
1015 010234  000047  000051  000053          .WORD 47,51,53,54,56
     010242  000054  000056
1016 010246  000060  000062  000063          .WORD 60,62,63,65,67
     010254  000065  000067
1017 010260  000071  000073  000075          .WORD 71,73,75,100,102
```

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SPECKLEGRAM ANALYSIS SYSTEM
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     010266  000100  000102
     010272  000104  000107  000111          .WORD 104,107,111,114,117
     010300  000114  000117
     010304  000121  000124  000130          .WORD 121,124,130,133,136
     010312  000133  000136
     010316  000142  000146  000152          .WORD 142,146,152,156,163
     010324  000156  000163
     010330  000170  000175  000203          .WORD 170,175,203,211,217
     010336  000211  000217
     010342  000226  000236  000246          .WORD 226,236,246,257,271
     010350  000257  000271
     010354  000304  000321  000337          .WORD 304,321,337,356,400
     010362  000356  000400
     010366  000425  000455  000511          .WORD 425,455,511,552,624
     010374  000552  000624
     010400  000707  001011  001140          .WORD 707,1011,1140,1333,1623
     010406  001333  001623
     010412  002305  003450  007122          .WORD 2305,3450,7122,0
     010420  000000



     010422  000000  000001  000002  SINBUF:.WORD 0,1,2,4,5,6
     010430  000004  000005  000006
     010436  000007  000010  000012          .WORD 7,10,12,13,14,15
     010444  000013  000014  000015
     010452  000016  000017  000020          .WORD 16,17,20,21,22,23
     010460  000021  000022  000023
     010466  000024  000025  000026          .WORD 24,25,26,27,31,32
     010474  000027  000031  000032
     010502  000033  000034  000035          .WORD 33,34,35,36,37,37
     010510  000036  000037  000037
     010516  000040  000041  000042          .WORD 40,41,42,43,44,45
     010524  000043  000044  000045
     010532  000046  000047  000050          .WORD 46,47,50,51,51,52
     010540  000051  000051  000052
     010546  000060  000061  000061          .WORD 60,61,61,62,63,63
     010554  000062  000063  000063
     010562  000064  000065  000065          .WORD 64,65,65,66,66,67
     010570  000066  000066  000067
     010576  000067  000070  000071          .WORD 67,70,71,71,72,72
     010604  000071  000072  000072
     010612  000072  000073  000073          .WORD 72,73,73,74,74,74
     010620  000074  000074  000074
     010626  000075  000075  000075          .WORD 75,75,75,76,76,76
     010634  000076  000076  000076
     010642  000076  000077  000077          .WORD 76,77,77,77,77,77
```

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SPECKLEGRAM ANALYSIS SYSTEM

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     010650  000077  000077  000077
1043 010656  000077  000077  000077         .WORD 77,77,77,77,77,100,0
     010664  000077  000077  000100
     010672  000000
1044
1045
1046
1047 010674  001000  000775  000766  COS:   .WORD 1000,775,766,752,731;     COSINE TABLE
     010702  000752  000731
1048 010706  000704  000652  000622         .WORD 704,652,622,552,505
     010714  000552  000505
1049 010720  000435  000361  000304         .WORD 435,361,304,224,144
     010726  000224  000144
1050 010732  000062  000000                 .WORD 62,0
1051 010736  177716  177634  177554         .WORD 177716,177634,177554,177474,177417
     010744  177474  177417
1052 010750  177343  177273  177226         .WORD 177343,177273,177226,177156,177126
     010756  177156  177126
1053 010762  177074  177047  177026         .WORD 177074,177047,177026,177012,177002
     010770  177012  177002
1054 010774  177000  177000                 .WORD 177000,177000
1055
1056
1057
1058 011000  000000  000062  000144  SIN:   .WORD 0,62,144,224,304;         SIN TABLE
     011006  000224  000304
1059 011012  000361  000435  000505         .WORD 361,435,505,552,622
     011020  000552  000622
1060 011024  000652  000704  000731         .WORD 652,704,731,752,766
     011032  000752  000766
1061 011036  000775  001000  000775         .WORD 775,1000,775,766,752
     011044  000766  000752
1062 011050  000731  000704  000652         .WORD 731,704,652,622,552
     011056  000622  000552
1063 011062  000505  000435  000361         .WORD 505,435,361,304,224
     011070  000304  000224
1064 011074  000144  000062  000000         .WORD 144,62,0
1065
1066
1067         000500'                        .END START
```

SPECKLEGRAM ANALYSIS SYSTEM

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SYMBOL TABLE

A	005630	AAMP	004076	AANGLE	003760
ADISP	004424	ADO	001506	AFFT	001462
AFREQ	004516	AG1	002304	AG2	002324
AG3	002366	ALOAD	002626	ALOOP	003552
ALPHA	001706	AMANIP	001246	AMP	004100
ANGLE	003762	APRINT	003640	AREAD	003216
ASCII	001034	ASKAV	006062	ASTAGE	005132
AVER	003372	AZERO	002154	B	005632
BDO	001510	BEGIN	003060	BETA	001736
BZERO	002314	C	005634	CDO	001606
CHECK	002454	CIRCLE	003622	CLEAR	000562
CLOCK1	003224	CLOCK2	003300	CLOCK3	003330
CLOCK4	003344	CLOCK5	003436	CLR1	001254
CLR2	001270	CMST	001230	COLM	005730
COS	010674	CYCLES	006772	CZERO	002576
D	003052	DATA	010046	DBUF	005702
DBUFCL	004056	DCLEAR	005506	DELAY	005726
DIVANG	004050	DNREAD	003516	DOCIR	004010
DOLOOP	005416	DONE1	003240	DONE2	003360
DONE3	003452	DOT	002556	DOWN	001576
DROP	001572	DUPPED	003566	DWIPE	004500
DZERO	002442	EAT	002516	ECHO	004340
EOL	006756	E1	004374	FBUFAV	007022
FFT	001464	FFTBUF	007434	FIN	006460
FLG	005664	FOW	004660	FOWARD	003602
FREQ	004520	FUD1	002214	FUD2	002334
FUD3	002464	FUD4	002636	FUNC	005650
F3	001452	F4	001442	GAMA	001776
GOOF	006444	GOON	002174	GOONY	002616
HEAD	006576	HIDC	005734	HIGH	002566
HOLD	004564	HOP	004542	HUMPS	001356
INCX	006026	INCY	006042	INPUT	004320
JUG	002246	JUGGER	002670	JUMP	000556
KBB	= 177562	KBS	= 177560	KEEP	005666
KILL	001714	LESS	004746	LESSOR	004462
LINE	005724	LIST	004710	LNFD	004406
LOAD	002204	LOOKUP	004030	LOOP1	003426
LOOP2	003510	LOW	002610	L10.	002752
L11.	002766	L12.	003016	L3	001770
L5	002026	L6	002074	L7	002374
L8.	002674	L9.	002724	MANIP	001250
MEAN	005762	MINUS	002166	MORE	004704
MULT1	003774	MULT4	002432	MULT6	004444
NOLIST	001376	NONE	005642	NORMAL	001474
NOTE1	004130	NOTE2	004152	N1	004246
N2	004262	N3	004276	N4	004312
OBUF	005644	OPER	004232	OTD	004754

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SPECKLEGRAM ANALYSIS SYSTEM

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SYMBOL TABLE

OTHER   002134          OVER    004752          PC     =%000007
PLUS    002144          POSITN  005502          PRINT   003642
QUES    010100          QUIT    004640          RATHER  005746
RATIO   005754          READ    003220          RECLR   003176
ROBUF   005756          ROUND   005446          RR0     005604
RR1     005606          RR2     005610          RR3     005612
RR4     005614          RR5     005616          RR6     005620
RR7     005622          RR8     005624          RR9     005626
R0     =%000000         R1     =%000001         R2     =%000002
R3     =%000003         R4     =%000004         R5     =%000005
SECOND  005640          SEE     001544          SHIFT   001660
SIN     011000          SINBUF  010422          SKIP    004610
SLIDE   003120          SLIP    001616          SLOW    003316
SP     =%000006         SPC     006742          SQCZ    005732
SQR1    004110          SQR2    004116          SQR3    004124
SQR4    004140          SQR5    004162          SRCH    004550
STAGE   005134          START   000500          STEPX   006056
STEPY   006060          STORE   001502          TANBUF  010134
TEST    003112          TIMES   005744          TPB   = 177566
TPS   = 177564          TRACK   005742          TTYOUT  004310
UNIT    005722          UP      001552          VALID   004622
WAIT    003276          WHICH   005740          X       005636
XDIST   006144          XDISTO  005750          XINC    006324
XLIMIT  005776          XLOOP   005176          XREAD   005736
XSTEP   005154          XZERO   005402          YDIST   006234
YDISTO  005752          YINC    006374          YLIMIT  006012
YLOOP   005310          YSTEP   005266          ZEROX   005374

. ABS.  011102    000
        000000    001

ERRORS DETECTED:  0
FREE CORE:  4851. WORDS
DC:RL.OBJ,LP:LIST<DT1:RL.SRC
```

APPENDIX III

SYSTEM OPERATING INSTRUCTION

OPERATING PROCEDURES:

I. The initial set-up should be performed as follows:

1. A 15 milliwatt or greater He-Ne laser should be aligned on the centerline of an optical bench, 8.75 inch above the surface of the bench, with all of the optics centered on this beam.

2. Set up the beam-reducing optics as described in the Optical Setup Section of this report and insert an optical attenuator immediately following these optics.

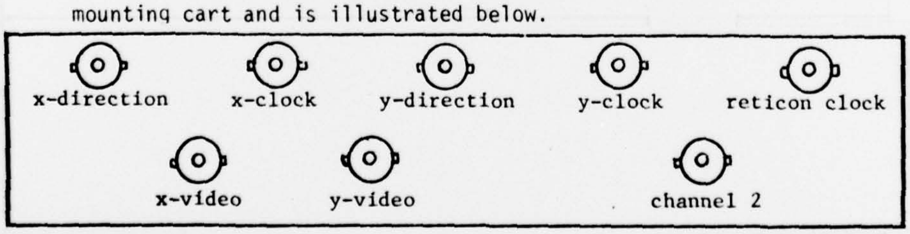
3. Place the x-y stage as close to the attenuator as needed.

4. Align a ground glass screen, with a D.C. spot block, so that the D.C. component of the fringe halo image falls on the block. Position the ground glass in the optical axis direction so that a fringe halo of 2-4 inches in diameter exists.

5. An imaging lens (f=28mm) should be centered on the optical axis and positioned to image the fringe pattern onto the detectors. The distances between the lens and the detector all depend upon the image aperture of the specklegram recording system. Essentially for the fringe spacing of a given specklegram to be analyzed accurately, the readout halo size depends on the recording aperture.

6. Connect the x-y stage cables to the appropriate x-y Aerotek Drive Units via the 8 pin connector plugs.

7. A labeled BNC wiring panel is attached to the top back of the rack mounting cart and is illustrated below.



A list of to and from BNC connections are shown in the following table:

WIRING DIAGRAM	
FROM	TO
Aerotek Drive-(x) DIR	Panel - x - direction
Aerotek Drive-(x) CL	Panel - x - clock
Aerotek Drive-(y) DIR	Panel - y - direction
Aerotek Drive-(y) CL	Panel - y - clock
Reticon -x video	Panel - x - video
Reticon -y video	Panel - y - video
Reticon -Ext. clock	Panel - reticon clock
Reticon -EOS	Panel - channel 2

8. AC connections from the Aerotek Drive Units, PDP 11 computer, off-on indicator light, and control electronics panels should be plugged into the AC terminal strip in the lower rear of the rack mounting cart.

9. Connect the teletype I/O to the computer I/O cable and plug the teletype into a wall socket.

10. Turn on all equipment and check out this equipment with a test paper tape given to you by AFAL/DHO-2.

II. AFTER CHECK-OUT (Initializing for a read sequence)

1. Place Specklegram into 4 inch by 5 inch holder.
2. Align the readout beam to the upper right hand corner of the specklegram plate, (facing the plate), by setting the local-remote switch on the x drive unit to the local position and pushing the slew button until the upper right hand x position is reached. The + or - switch will be set according to the initial position of the plate before setting up. The slew speed can also be changed by the small potentiometer on the front panel. Repeat for the y-position.
3. Reset the x and y digital display to zero by depressing the reset button and switch the remote-local switches to the remote position. The system is now ready for computer control operation.

4. Load the control program through the paper tape reader on the teletype by the following procedure:

A.) If the Bootstrap loader is not contained in core-memory, a hand loading procedure is as follows:

a.) Toggle in 017744 onto the computer switches and hit LOAD ADDR Button.

b.) Toggle 016701 and hit the DEP button and continue DEP operations on these numbers: 000026, 012702, 000352, 005211, 105711, 100376, 116162, 000002, 017400, 005267, 177756, 000765, 177560, 000000.

B.) Set the ABSOLUTE LOADER paper tape into the reader with the leader section in the reader section, and set the reader switch to the top position called START.

C.) 017744 and LOAD ADDR then START. The Absolute loader should now pass through the reader and stop when finished.

D.) Load the Control tape into the reader with the leader positioned in the reader section, and set the read switch up.

E.) 017500 and LOAD ADDR then START. The control tape should now pass through the reader and stop when finished. The control program is now loaded.

5. Make sure all connections are made and all power switches are activated. The program is now ready to run.

6. 000500 and LOAD ADDR, then START.

7. The teletype will now ask initializing questions before displaying specklegram data and these questions can be answered as described in the Software Section of this report. When the data run is finished, the teletype will print "SCAN COMPLETED".

8. If, before shutdown, another plate is to be analyzed, only the following steps have to be repeated:

II. - 1,2,3,6

9. The computer can be stopped during any phase of operation by simply hitting the HALT Button and after a data run there is no specific shutdown sequence except that the HALT button should be activated before shutting any other power off.

10. Once the procedures of Sections I and II of the operating procedures have been performed complete, only steps II. - 1, 2, 3, 4B, 4C, 4D, 4E, 5, and 6 have to be repeated.

APPENDIX IV

A TYPICAL SPECKLEGRAM EXPOSURE AND READOUT

Appendix V is designed to inform the reader in brief of a typical experiment run through from initial exposure to final readout, with the understanding that specific details can be obtained from the references listed at the end of the report.

1. EXPOSURE

In recording speckelgram data, if the laser has a wavelength of 5140 angstroms and the lens has an f-number equal to 2, then the speckle size projected onto the film plane is approximately 1 micrometer, which is defined as the minimum speckle size for our purposes. This minimum sets one parameter related to the system resolution. The next question related to the system resolution is what is the maximum and minimum shift that can be tolerated? Sampling Theory requires that the shift be greater than 2 speckle sizes (2 micrometers). The maximum shift is defined by requiring the shift not to be larger than the readout beam size (.5 to 1 millimeter). The reason for this maximum is that the surface across the reading aperture can be shifted in only one direction with the randomness of the speckle remaining unchanged. The exposure time required on the film plane is proportional to the film sensitivity and for a typical film (Kodak 649-F), 500 ergs/cm^2 is needed. Assuming now for simplicity a square centimeter of gray steel (55% reflectivity) as a specimen, a 50 milliwatt laser as an illuminator source, in which all of the light intercepts the 1 cm^2 area, and a cosine reflection distribution from the specimen with 1% of the reflected light reaching the imaging lens, a typical exposure might be as follows:

$$1000 \text{ ergs} = 10^{-4} \text{ watt-sec}$$

$$500 \text{ ergs} = .05 \text{ milliwatt-sec}$$

$$.05/50/.55/.01 = .18 \text{ seconds}$$

The .18 second exposure time assumes ideal conditions, thus optical losses in the system would require more exposure time.

The processing required is the standard film process:

1. Develop (D-19) - 6 minutes
2. Stop (Stop Bath) -30 seconds
3. Fix (Rapid Fixer) - 5 minutes

The plate is now ready for readout.

2. READOUT

Readout techniques used for extracting the fringe information from a specklegram and a typical fringe halo are, for the purposes of this report, as follows. A 1 mm readout beam diameter is chosen, thus providing a maximum of 13000 data points on one 4 inch by 5 inch film plate. Since the readout procedure for each point is the same, the procedure for only one point will be discussed. The halo containing the fringe information is defined as a conical ray of light diverging from the center of the readout beam with a cone angle directly calculatable from the recorded speckle size as follows:

$$2\lambda/D = \theta$$

where D=the speckle size. If D=1 micrometer and λ = .5 micrometer, then θ = 1 radian.

Since the recording speckles are arranged in a random fashion and the speckle shift is in only one direction over the area defined by a 1 mm aperture, then the analogy can be made that the random speckle shift acts similarly to a double slit optical configuration.

The equation for the double slit is

$$n\lambda = 2d \sin \theta$$

where n is the order of the fringe, λ is the wavelength of light, d is the distance between slits (or speckle correlation shift) and θ the angle of the fringe transmission.

This says that the first dark fringe should be located at an angle of

$$\theta = \lambda/2d$$

if θ is a small angle.

It should be obvious at this point that the specklegram strain analysis technique is an excellent tool for looking at in-plane displacements or strains parrallel to the recording surface, while holographic interferometry best applied to out-of-plane measurements; thus the two techniques should complement each other for solving many strain and stress problems existent in the Air Force.

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